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ANALYTICAL STUDY OF COCKPIT INFORMATION REQUIREMENTS.(U)
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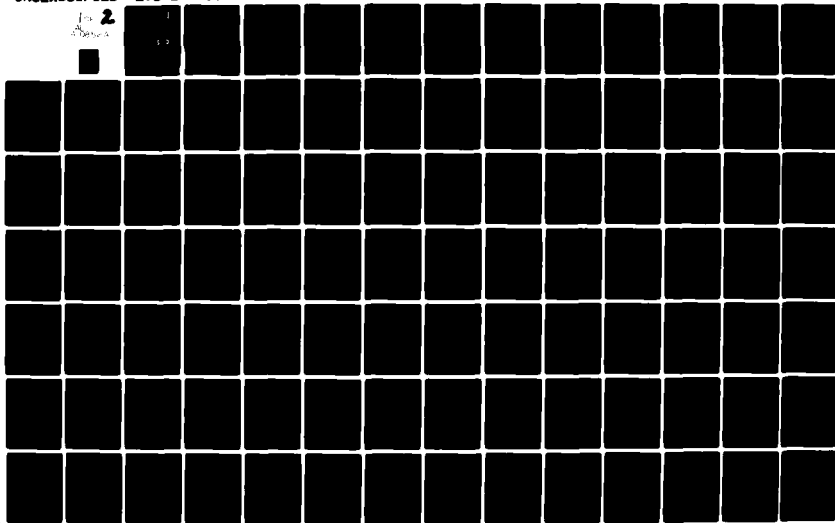
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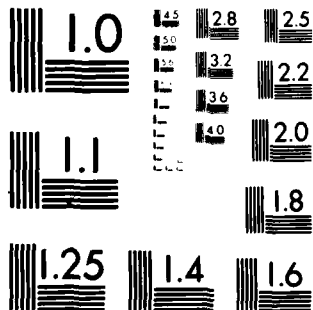
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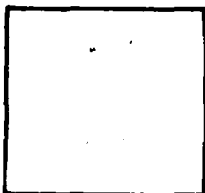


MICROCOPY RESOLUTION TEST CHART
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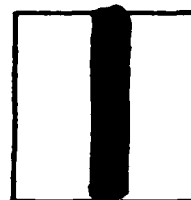
AD A108524

DTIC ACCESSION NUMBER



LEVEL

Lockheed Georgia Co.
Marietta



INVENTORY

Analytical Study of Cockpit Information Requirements
Final Rpt., Oct. 79 - Nov. 80 Apr. 81

DOCUMENT IDENTIFICATION

Rpt. No. LG80ERO200

Contact DOT-FA 79WA-4368

DOT/FAA/RD-81/4

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Analytical Study of Cockpit Information Requirements

J. D. Caldwell
T. G. Jones

Lockheed — Georgia Company
86 South Cobb Drive
Marietta, Georgia 30063

April 1981

Final Report

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U.S. Department of Transportation
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Washington, D.C. 20590

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Technical Report Documentation Page

1. Report No. DOT/FAA/RD-81/4	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle ANALYTICAL STUDY OF COCKPIT INFORMATION REQUIREMENTS		5. Report Date April 1981	
		6. Performing Organization Code	
7. Author(s) J. D. Caldwell, T. G. Jones		8. Performing Organization Report No. LG80ER0200	
9. Performing Organization Name and Address Lockheed-Georgia Company 86 South Cobb Drive Marietta, Georgia 30063		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DOT-FA79WA-4368	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590		13. Type of Report and Period Covered Final Report October 1979 to Nov. 1980	
		14. Sponsoring Agency Code ARD-300	
15. Supplementary Notes			
16. Abstract <p>An assessment is made of cockpit information requirements likely to be imposed on aircraft in the next fifteen years as a result of improvements in the ATC system and in aircraft design. These requirements are analyzed by work centers and include flight control, navigation, collision avoidance, flight management, communications, caution/warning & monitoring, and checklist functions. From a baseline of current requirements and technology, the application of new requirements and technology is analyzed. Three aircraft are hypothesized representing three time periods of technical development. The purpose is to investigate the impact of future ATC changes on differently equipped aircraft. The Advanced Integrated Aircraft incorporates technologies that are projected to be practical in the 1990s which make extensive use of electronic displays and have a high degree of integration using advanced data bus systems. The Intermediate Aircraft is of contemporary advanced design with a mix of electronic and electromechanical displays, digital electronic equipment, and current standard data buses. The Electromechanical Aircraft is representative of older generation aircraft having electromechanical displays, mostly analog electronic equipment, dedicated controls, and hard-wired interconnections. Appendices of supporting data are included.</p>			
17. Key Words Cockpit Information Advanced Systems Aircraft Data Buses Cockpit Integration Advanced Displays/Controls		18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 161 170	22. Price

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2000 lb)			
VOLUME				
teaspoon	teaspoons	5	milliliters	ml
Tablespoon	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cup	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m ³
cu yd	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
ha	hectares (10,000 m ²)	0.4	square miles	mi ²
		2.5	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	cu ft
m ³	cubic meters	1.3	cubic yards	cu yd
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



* 1 in = 2.54 (exact). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, *Units of Weights and Measures*, Price \$2.25, SO Catalog No. C-13-10286.

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LIST OF ABBREVIATIONS

A/C	Aircraft
ACARS	ARINC Communications Addressing and Reporting System
ACS	Active Control System
ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
A/G/A	Air/Ground/Air
AIDS	Aircraft Integrated Data System
A/L	Autoland
ARINC	Aeronautical Radio Incorporated
ARTC	Air Route Traffic Control
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATARS	Automatic Traffic Advisory and Resolution Service
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Automated Terminal Information Service
ATS	Automatic Throttle System
CAS	Calibrated Airspeed
CAT	Clear Air Turbulence
CAWS	Caution, Alerting, and Warning System
CDTI	Cockpit Display of Traffic Information

CDU	Control Display Unit
CDWI	Cockpit Display of Weather Information
CRT	Cathode Ray Tube
CWMCS	Caution/Warning, Monitoring and Checklist System
DABS	Discrete Address Beacon System
DOD	Department of Defense
DME	Distance Measuring Equipment
EADI	Electronic Attitude Director Indicator
ECS	Environmental Control System
EGT	Exhaust Gas Temperature
EHSI	Electronic Horizontal Situation Indicator
EPR	Engine Pressure Ratio
ETA	Estimated Time of Arrival
ETIS	Enhanced Terminal Information Service
FAA	Federal Aviation Administration
FF	Fuel Flow
FGD	Flight Group Display
FL	Flight Level
FLIPS	Flight Information Procedures
FMC	Flight Management Computer
FMS	Flight Management System

GA	Go Around
GMT	Greenwich Mean Time
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GS	Glideslope
HUD	Head-Up Display
IBS	Information Breakdown Structure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
I/O	Input/Output
IP	Initial Point
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LOC	Localizer
LORAN	Long Range Navigation Equipment
MLS	Microwave Landing System
MSAW	Minimum Safe Altitude Warning
NASA	National Aeronautics and Space Administration
NAVAIDS	Navigation Aids
NGD	Navigation Group Display
NOTAMS	Notice to Airmen

000I	Report of Time: Out From gate Off the departure runway, On runway at destination, and In to gate.
PIREPS	Pilot Reports
RA	Radar Altitude
RNAV	Area Navigation
2-D RNAV	RNAV Providing Lateral Guidance
3-D RNAV	RNAV Providing Lateral and Vertical Guidance
4-D RNAV	RNAV Providing Lateral, Vertical, and Time Guidance
RPM	Revolutions Per Minute
RVR	Runway Visibility Range
SELCAL	Selective Calling
SIDS	Standard Instrument Departures
S/O	Second Officer
STARS	Standard Terminal Arrivals
TACAN	Tactical Air Navigation
TRACON	Terminal Radar Approach Control
V1	Decision Speed - Equal options: Continue takeoff or stop.
VFR	Visual Flight Rules
VHF	Very High Frequency

VHSIC	Very High Speed Integrated Circuit
VOR	VHF Omni Range
VORTAC	Co-located VOR and TACAN Stations
VMC	Visual Meteorological Conditions
Vne	Never Exceed Speed
Vr	Rotate Speed - Speed at which an aircraft is rotated to its takeoff attitude
Vref	1.3 VS
Vs	Stall speed of aircraft
V/V	Vertical Velocity
WX	Weather

I. INTRODUCTION

The results of a one year study of cockpit information requirements are contained in this report. The study was done by the Lockheed-Georgia Company for the Federal Aviation Administration under Contract DOT-FA79WA-4368.

The objectives of the study were to develop current cockpit information requirements, to develop the additional information demands over the next fifteen years resulting from planned improvements in the Air Traffic Control (ATC) System and in aircraft systems, to develop options for handling these demands, and to develop integration schemes for bringing additional information into the cockpit without overloading any member of a flight crew.

The data base used for this study was developed from many sources. The amount of material used makes it impossible to acknowledge all sources of information and insight given to the authors in the course of the study. A bibliography has been included of some of the more pertinent references. Literature searches were made to confirm the validity of our own technical knowledge and to surface any new information bearing on cockpits. Contacts were made with a local airline. Visits were made to the Atlanta Tower and the Air Route Traffic Control Center (ARTCC) at Hampton. Trips were made to the Dallas/Fort Worth Tower and ARTCC. To gain first-hand information on current procedures and problems, five people working in the advanced cockpit area made 22 flights covering over 50 legs as cockpit observers with a local major airline. Many telephone contacts were made with equipment suppliers and the study benefitted from many supplier briefings instigated by a new aircraft program at Lockheed-Georgia. Support was provided by the Lockheed-California Company. A NASA Langley briefing "1980 Aircraft Safety and Operating Problems Conference" provided valuable input. Input was obtained from the FAA sponsored "Aircraft Alerting Systems Standardization Study" under Contract DOT-FA79WA-4268.

Special recognition and grateful acknowledgement is made here of the many FAA contributions to the study. Briefings were held in Washington where many specialists in advanced technical areas discussed their programs. A large amount of documentation on these programs was supplied. Our special thanks to Mr. Robert Wedan - Director of SRDS and to Mr. Sieg Poritzky - Director of OSEM for their support and helpful suggestions; to Mr. Patrick Russell - SRDS, who was the Technical Officer for this program until his retirement, and to Mr. Richard Weiss, who replaced him, for their unstinting efforts in furnishing documentation, reviewing material, and providing program coordination; to Mr. Peter Hwoschinsky - OSEM, whose insights and helpful suggestions were invaluable; to Mr. John Parks - SRDS for his assistance and comments during program reviews; to Capt. Larry Wood, USAF, for his HUD and windshear contributions; and to Mr. Harry Verstynen - OSEM, Chief - FAA Technical Field Office at NASA Langley who originated the study requirements.

II. APPROACH

The contract required that the study be done in three phases. The objective of Phase I was to develop the Information Breakdown Structure (IBS) to provide a logical format for collecting the cockpit information requirements developed in the later phases. The IBS format was developed around the fact that cockpit tasks are the generators of cockpit information requirements. In turn, these cockpit tasks are generated and scheduled by the phase of operation an aircraft is in at any particular moment, e.g. engine start, taxi out, etc. Performance of cockpit tasks involved aircraft functions, e.g. navigation, aircraft guidance/control, propulsion, etc. The IBS was developed around "Flight Phase" as the independent variable and followed by the dependent variables of "Tasks", the "Information" required to do these tasks, and what aircraft "Functions" are involved in each of the tasks. Provisions were made in the IBS "Information" section to record information content, its source, and the flight crew member or members who process it. Provisions were also made for classifying information as to its relative importance and whether or not it is sensitive to ATC changes.

The objective of Phase II was to develop cockpit information requirements covering the next fifteen year time period. Several sources were used to define these requirements. The FAA provided ATC development scenarios for the 1985, 1990 and 1995 time periods. Lockheed generated aircraft development scenarios for the same time periods. The aircraft scenarios are contained in Appendix A of this report. Cockpit information requirements by flight phase are contained in Appendix B in an IBS format. To further define requirements, Lockheed developed worksheets to expand the requirements for future systems, both ATC and aircraft. These worksheets contain among other data an estimate of dates these systems will be operational along with input/output requirements and options for meeting these requirements. The worksheets are included in this report as Appendix C.

The objective of Phase III was to analyze the information requirements developed in Phase II to determine possible schemes for integration of this information into jet transport cockpit systems which are compatible with human capabilities and limitations. The approach to Phase III was to do an information analysis on major work activity centers in the cockpit e.g. Flight Control Group, Navigation Group, Communications Group, etc. in order to bring out how these are likely to change in the future. The analysis provided the background for developing three integration schemes to implement the future systems: an advanced integrated aircraft, a contemporary digital aircraft using ARINC 700 series equipment including a flight management system with electronic flight display, and an older generation aircraft with electromechanical instruments.

III - INFORMATION ANALYSIS

This analysis examines cockpit information by major functional categories. These are: Flight Control, Navigation, Collision Avoidance, Flight Management, Communications, Caution, Warning, Monitoring, and Checklists. The cockpit as it has evolved today is discussed. Cockpit information is examined in the context of requirements, acquisition, processing, and use. Some of the shortcomings of current design are noted. The implications and potential problems resulting from the introduction of new or altered functions that are generated by future ATC and aircraft changes are discussed and some possibilities for their accommodation are contained in this section.

FLIGHT CONTROL FUNCTIONS

The Flight Control functions provide the interface between the pilot and the aircraft which enables him to observe and control the attitude and the flight path. Control in modern aircraft is exercised through various degrees of automation ranging from hydraulically-boosted manual operation of the control surfaces to fully automatic flight from takeoff to touchdown. Input methods include strictly manual inputs through column, wheel and rudder pedals, stability augmented systems which provide improved handling qualities, direct autopilot inputs, horizontal and vertical path selection through navigation control panels, and programmed flight using an area navigation system. The trend toward diminishing use of manual primary controls is being reflected in reduced physical size since the acceptance of hydraulic boost has eliminated the justification for a large, display obscuring yoke. During this decade, we will certainly see the yoke grow smaller. It is likely that it will be replaced with a center stick on many aircraft and possibly a chair arm control on the more advanced. Similar reductions in size and relocation should be expected for the throttles, flap handle, gear handle and speed brake. Automation, which is already well under way for the throttles, is not unlikely for the others.

Traditionally, the attitude indicator has provided an artificial horizon indication of pitch and bank and a ball-in-vial turn coordination indication. More sophisticated instruments provide computed lateral and vertical steering commands, lateral and vertical deviation, crab angle and a rising runway indication of radar altitude. Frequently a provision was made for pitch reference adjustment to compensate for instrument parallax or aircraft trim. Indicated airspeed and mach were usually displayed on an adjacent indicator as various combinations of analog and/or digital presentations. Barometric altitude and the reference pressure were presented on still another instrument with provision for reference pressure setting. Additional indicators have been provided for vertical velocity and radar altitude. In general, it has been necessary for a pilot to monitor three to five instruments to maintain a desired approach path during an instrument landing. This layout serves quite well under moderate IFR conditions, but when workloads are increased by weather, traffic, turbulence, failure conditions, internal communications requirements, ATC requests, and wind

variations the situation may become marginal at best.

This problem is compounded if any additional monitoring or scanning requirements outside the standard "T" group are added. The alerting and warning facilities of some older aircraft were distributed throughout the cockpit, creating the potential for overlooking alerts occurring under high workload conditions. Even the aircraft with centralized annunciator panels require substantial visual concentration to interpret. To some extent this problem is alleviated by giving responsibility for monitoring to other members of the crew but even this breaks down in high stress circumstances. Either the responsible crew member becomes absorbed in other activities or is unable to command the attention of the captain.

Research in the area of cockpit alerting and warning concepts has suggested that all but the most significant warnings should be eliminated from the pilot's consideration during critical flight phases and that essential warnings be presented on or adjacent to the primary flight display. An approach of this sort would eliminate distractions which could have more serious consequences than the condition annunciated, but would increase sensitivity to critical warnings.

The efficiency of the pilot can be improved by providing information which is in a directly usable form. This generally has not been done and would not be practical with electromechanical instruments. Pitch has been provided when flight path angle might be better. IAS has been displayed when angle of attack may be the critical information. As flight path adherence becomes more important, workload will increase accordingly unless better information is provided. Profile descents, curved approaches and the recognition of windshear hazards have demonstrated the need for more explicit flight path control information. Efforts to combine the functions of both vertical and horizontal situation indicators to provide a single integrated display have shown promise in several test programs. This approach has been used with both head up and head down electronic displays. By providing directly usable information in a manner naturally suggesting the proper response and by reducing scan requirements the proposed formats should reduce the cognitive as well as the visual workload.

Several auxiliary functions of the airspeed/mach indicator currently in use require consideration in future approaches. In addition to airspeed and mach indications, the conventional electro-mechanical devices currently in use provide some additional information to the pilot. Prior to takeoff V_1 , VR and V_2 speeds are calculated by the flight engineer and then set into and displayed on the airspeed indicators as movable markers around the perimeter. These markers not only serve as references for the pilots, but also provide anticipating cues as the speeds are approached and command indicators as they are passed.

An EADI digital airspeed display could provide the reference functions by additional digital indications. The command indications could be accomplished by color changes or by displaying a large V_1 , VR and V_2 . The result however would probably not be as satisfactory as the old method. Certainly more concentration would be required to react smoothly to the abrupt annunciation.

Maximum airspeed as a function of altitude as presently displayed on the airspeed indicator may be displayed on the EADI. This also would probably be less meaningful if displayed digitally than graphically. Other similar airspeed functions which should be considered for display during appropriate flight phases are V_s , the aircraft stall speed and V_{ref} for approaches under anticipated windshear conditions.

A more desirable approach to the problem of displaying limits, decision points and commands might be to graphically generate an airspeed scale with the appropriate markers and either a pointer or a rising bar to indicate speed. A digital readout may be retained to provide precision airspeed indications, eliminating the need for and clutter of graduations.

By utilizing the flexible nature of the electronic display, the changing requirements of airspeed indication with each flight phase can be met without compromising the formats required for other situations. When combined with the capabilities of the flight management computer, a system may be created which provides upper and lower limits, commanded airspeed for adhering to fuel or time schedule as well as current airspeed and mach. Consideration should also be given to integrating flap retraction and extension schedules into the airspeed graphical display.

Altitude indications have previously been handled by a barometric altitude indicator displaying altitude in digital and analog form and the barometric reference pressure upon which the altitude is based. Above 18,000 feet the barometric reference is set to 29.92 inches. An altitude monitor display is provided which provides an indication when the aircraft approaches or departs the altitude selected. A radar altimeter is available which displays altitude above the terrain up to 2500 feet with facility to enter decision height as a scale marker which provides an alert when that altitude is approached. The radar altimeter may also drive a runway symbol which rises beneath the ADI aircraft symbol to provide touchdown anticipation. Some displays switch to radar altitude below 200 feet.

The electronic display provides the format flexibility to incorporate integrated flight control display concepts even if they are developed after production of the aircraft. Unfortunately this option will probably not be available to the electromechanically instrumented aircraft unless a significant breakthrough in flat panel technology takes place. Because of the depth requirements of CRT displays retrofit seems impractical.

Further improvement for flight control display efficiency may result from combining the advanced flight path concepts with color. The recognized advantages of color for prioritization, data separation and added dimensionality should apply equally well here as with conventional EADI and EHSI formats.

Several technological advances appear promising for future transport application of headup displays. Diffraction optics techniques allow considerably greater external image and display image brightness by selective reflection of only the light wavelength of the display phosphor. The result is a better view of the outside world and longer CRT life. Another potential improvement is the use of the wind screen itself as the combiner. This reduces multiple images caused by reflections and increases external image

brightness by eliminating surfaces. This technique provides further benefits by eliminating additional supporting frames and stabilization struts. The major constraints here are the angular relation between the optics, the windscreen and the pilots eyes as well as the space required in the crowded glareshield area.

The new systems proposed for the next decade impose additional requirements on the flight control instrument group which must be considered in the context of both aircraft and human characteristics.

The DABS Data Link will shift a significant amount of aural workload to the visual channel if that presentation option is selected and a portion of this workload involves the flight control and critical warnings information categories. The various clearance functions could be annunciated in a visually convenient location for observation under both VFR and IFR conditions. Minimum safe altitude and conflict resolution messages require immediate response under all circumstances and should be located accordingly. Significantly, the most likely time for these annunciations is during terminal area flight under instrument conditions, making a primary flight display presentation desirable unless an aural word generation is used.

Windshear warning and resolution represents another example of flight critical warning and guidance information. Again immediate action is required and is likely under instrument conditions. The necessity to elicit rapid reactions which tend to contradict normal responses provides a severe challenge to the flight station instrumentation designer. Early warning of potentially hazardous conditions and the automatic calculation of modified reference airspeed and groundspeed would be of considerable value to the pilot, as would be the determination of the necessity of a go-around when the requirements for safe flight threaten to exceed the aircraft's acceleration potential. Complete display requirements are, as yet, undefined, but the need for windshear warning and go-around annunciations seem appropriate. Fast/slow indications, thrust commands and pitch commands might be used to provide the pilot with resolution information. Potential flight path displays are also of interest in this regard.

The Microwave Landing System (MLS) will probably be used by large, passenger carrying aircraft in much the same way as the present ILS for some time. The potential exists, however, for the use of steep, curved approaches especially for some commuter and some general aviation aircraft. Primary display requirements for these aircraft might become severe. A somewhat less demanding application of MLS provides a segmented approach capability which appears attractive for noise abatement and obstacle avoidance. The potential flight path display is particularly attractive here.

NAVIGATION FUNCTIONS

The Navigation Group provides the information needed by the pilot to either carry out his navigation objectives himself or to monitor the automatic execution of his navigation plan. The problem of air navigation is, primarily, to determine the direction necessary to accomplish the intended flight, to locate positions, and to measure distance and time as a means to that end. In addition to navigation information, other data

pertinent to carrying out a navigation plan is required. Knowledge of the situation outside of the aircraft such as obstacles in the flight path, be it other aircraft, terrain, or storms is necessary for modifying the navigation plan. Some of this information, because of its direct relationship and acceptability to navigation displays, is logically put in the Navigation Group. Information that is internally developed in the aircraft, such as the navigation aids in use, the mode of operation, and related matters belong with the Navigation Group.

Basic Navigation Information

Information is needed on the course in use, the current position of the aircraft along track and cross track relative to the desired course, and time and distance to the next navigation waypoint. A pilot should know at all times where he is and in what direction to proceed to reach his objective.

The desired course is specified by the flight plan or by modifications required by ATC directions or weather along the intended flight path. Facilities are therefore needed in the cockpit for convenient input and display of selected courses. Manual input of course selection is a basic requirement. Input may also be made automatically by a navigation computer operating from a prestored flight plan. The trend is toward automation for increased efficiency, reduced crew workload, and reduced blunder potential.

Course intelligence to guide an aircraft along a desired flight path may be obtained directly from VOR radials or from a navigation computer that is supplemented by an assortment of aids such as inertial, VOR/DME, GPS, and loran/omega. From these aids, the computer defines a navigation solution for the desired track of the aircraft and provides guidance for maintaining the track.

Course error information is needed in the cockpit for monitoring when on autopilot or for guidance during manual flight. Magnitude and direction information is required.

Progress along a flight path is measured in terms of present position and time. Progress may be expressed in absolute terms such as latitude, longitude and time, or in relative terms of distance and time to an active waypoint. Progress along a flight path may be determined by use of navaids or by a navigation computer. Operating from ground navaid facilities, position may be established directly by DME distance and "to-from" information when flying a VORTAC radial or by flying a line of position VOR radial to intersect a second VOR radial for the fix. Two DME distance measurements can establish position if the ambiguity can be resolved. ADFs can be used to establish position with a two bearing fix from broadcast or low-frequency stations. When navigation computers are used, present position information is available continuously to the flight crew.

Utilization of navaids by the flight crew in solving the navigation problem represents a workload in the cockpit. Tuning frequencies, selecting equipment and displays, verifying tuned stations by listening to their identification, position fixing from bearings, etc., all demand attention from the pilots. The trend is toward eliminating most of these tasks by the use of area navigation computers.

Additional Navigation Information Requirements

Additional requirements, other than basic navigation information, are placed on navigation displays and controls by current and future requirements. Since the primary navigation display is used in conjunction with the primary flight instrument to keep the pilot oriented to his horizontal situation, many of these requirements are best served by display on this instrument. The ability to do this in the past was constrained by electromechanical instrument limitations. Electronic displays have removed these constraints but have created other problems of clutter.

This section will consider collision avoidance, weather, RNAV/Flt Mgt systems and MLS as to their impact on the Navigation Group.

Collision Avoidance - There are three programs directly or indirectly involved with collision avoidance. These are: the Automatic Traffic Advisory and Resolution Service (ATARS), the Beacon Collision Avoidance System (BCAS), and the Cockpit Display of Traffic Information (CDTI). The objective of these systems is to put information into the cockpit on surrounding air traffic. ATARS is an automatic ground-based system which utilizes the DABS data link for transferring information to an aircraft on the location of proximate and threatening aircraft and issuing resolution advisories as needed. BCAS is an airborne beacon based collision avoidance system designed to operate in areas where no DABS-ATARS coverage is available. CDTI is a concept presently being evaluated by an FAA/NASA program having the objective of providing a pilot with information on aircraft in his vicinity for spacing and merging information, increased awareness of the air traffic situation, and for backup to the ground system.

ATARS - Current plans are to provide an aircraft with the following information on surrounding aircraft that are proximate but non-threatening: Bearing, Range, Altitude, Track, ATC Control Status, and ATARS Equipage. The above information locates the proximate aircraft, provides a general idea of their track, control status and whether or not they are ATARS equipped. Taken as a whole this is a great deal of information to introduce into the aircraft cockpit, especially for congested terminal areas.

Currently, pilots must depend almost entirely upon air traffic controllers for maintaining separation. Traffic advisories via voice communications provide pilot awareness of other aircraft in his vicinity. Advisories supplemented by visual observation is the present limit of information. This has proved to be an effective arrangement but controllers and pilots do have occasional lapses. The purpose of ATARS is to provide an automated and independent system to provide collision avoidance information in the cockpit.

The utility of the proximate advisory service of ATARS can only be determined by operational experience. It is probably more beneficial to pilots operating under VFR than those operating under IFR. The information is more positive and provides better range and altitude knowledge of targets than can be obtained visually. Relative altitude, for example, of target aircraft to own aircraft involving small angles are often impossible to judge visually at lower altitudes under the hazy conditions frequently encountered which obscure the horizon reference. This independent source of proximate

aircraft information should be useful to the VFR pilot in making his own threat assessment.

The benefits of traffic advisories to IFR pilots is not as clear. The system would be most active in heavily congested terminal areas where workload is high. Introducing additional information into the cockpit under these conditions, which does not contribute to pilot knowledge of what he should do, provide a source of potential distraction from other pressing duties. Proximate advisories may prove more beneficial on airways, however, where workload is lighter but passing traffic is heavy. Safety is enhanced by this added information.

The second level of ATARS is threat advisory. When one aircraft is projected to intrude into the protection area of another, additional information is sent to the two aircraft involved. A potential conflict is considered to exist when the time to closest approach point is estimated at less than 50 seconds, the horizontal miss distance is estimated to be less than 1.2 n. mi., and the vertical separation is estimated to be less than 1,000 feet. The additional information currently planned is projected miss distance.

Providing pilots the multi-dimensional information generated by a potential conflict situation with two dimension displays presents a problem in cockpit integration. Pilots need to be given a quick picture of the situation confronting them in order to anticipate and plan their actions. A sense of urgency needs to be conveyed - whether abrupt or routine maneuvers are likely to be required.

If plan view projected paths intersect, then relative altitude, time of intersection, and the horizontal position of the two aircraft at the time of closest approach is the primary information needed. If plan view projections do not cross, then the approach is of the greatest interest.

A threat advisory presents a stressful situation and the information transferred at this time to a pilot should be limited and easily absorbed. The threat advisory should therefore be examined as to its role.

The threat advisory, as was the case with traffic advisory, is expected to be more useful to VFR than to IFR operation. The other aircraft causing a threat will be identified and its point of closest horizontal approach predicted if the two aircraft continue their present courses and speeds. This information along with proximate aircraft information is useful in staying ahead of a developing situation for a pilot flying VFR. The use of threat advisories for IFR aircraft could introduce a factor in the cockpit that prolongs attention time demands, increases stress, yet does not advise the IFR pilot on what actions he should take. The usefulness of threat advisories for IFR operations needs to be verified by experience. It is important not to overload pilots with information during situations when quick and intuitive action is required.

It is felt that turning aircraft could present a problem to an automated system like ATARS by generating rapidly changing conflict information and indicating a potential conflict when none exists. The automated system has no intelligence on the intent of the turning aircraft and a potential

conflict alert may be generated that should not have been.

The third level of ATARS is the resolution service. The information consists of guidance to (1) Fly up or down, and (2) Turn left or right and/or negative equivalents of (1) Don't fly up etc. This type of information belongs in the primary flight group and is discussed under that heading.

Beacon Collision Avoidance System (BCAS) - Two programs are under development by the FAA. One is referred to as Active BCAS which was designed for early implementation. The second program, Full BCAS, is a more complex system having both active and passive modes which will require considerably longer to develop.

Active BCAS will operate in areas outside of DABS-ATARS coverage with all aircraft equipped with ATC beacons. Air-to-air interrogation of Mode C transponders provide range, range rate, altitude and altitude rate to the interrogating aircraft. Mode A provides only range and range rate.

An on-board threat evaluator determines when a proximate aircraft is a threat and outputs a vertical maneuver advisory. When operating against a BCAS equipped aircraft, maneuver coordination between the two aircraft is accomplished over the DABS data link.

The vertical maneuver advisories of Active BCAS belong with and are discussed under the Primary Flight Group.

Full BCAS is a long-term developmental backup program to ATARS and active BCAS for providing the collision avoidance function. It is designed for multiple mode operation that is dependent upon the type and geometry of ground surveillance radars and other aircraft equipment. Full BCAS will provide both vertical and horizontal maneuver advisories. It has potential for providing the sensor inputs for the Cockpit Display of Traffic Information (CDTI) concept. Since Full BCAS provides information in the cockpit similar to ATARS, the cockpit considerations discussed under ATARS are applicable to Full BCAS.

Cockpit Display of Traffic Information (CDTI) - CDTI is a generic concept with the goal of displaying air traffic information in the cockpit. This goal has been sought for many years to fill a gap in cockpit information by display of other aircraft in the vicinity.

The information required by CDTI is that required to locate aircraft relative to one's own aircraft plus that required to convey an awareness to the pilot of his tactical situation. Locating targets on the display would require little attention. More attention is required, however, to develop a picture of what each aircraft is doing and the situation implications of this. Target ranges and bearings are easily displayed on a plan-view electronic indicator. Altitude is more of a problem and labels or coding is generally used for this third dimension. Labels are a problem because of the display space required, the possibility of overlapping labels, and adding to display clutter. Aircraft identification could be handled in code letters of the target display and decoded elsewhere in the cockpit. Heading and speed are commonly handled by target vectors with rotation indicating heading and length indicating speed. To complete the picture of what each target is

doing, changes in altitude of each target must be acquired. Developing and keeping abreast of the flight situation requires pilot attention and concentration and therefore increases workload. Keeping ahead of the developing situation, once acquired, should not prove difficult for a pilot as long as he does not maneuver his aircraft. Maneuvering, however, will shatter the picture and require re-orientation to his new post maneuver reference if the present fixed aircraft/moving outside world is used. There was insufficient time to pursue the ramifications of a different approach which would eliminate the problem of reacquiring a situation display after a turn. This concept is as follows:

Conventional map type displays have a fixed aircraft and a moving outside world with aircraft track up. The targets move from top to bottom as the aircraft progresses on its track. When the aircraft is turned, the computer rearranges every data point on the picture to its new position along the new ground track which has remained fixed on the display along with the aircraft symbol.

An alternative to this is to have a north-up display, where in a turn, the outside world is left as it is and the aircraft's track and symbol are rotated. The computer moves the maps and targets along the new ground track. This arrangement has the effect of making the pilot an outside observer of his own aircraft and the entire scene. When he turns, only his aircraft and track line appear to move instantaneously. Every other element appears to stay in the same position. Having the track display at any position of the compass rather than dead ahead may be disconcerting at first but it is believed that having air traffic targets stay put in turns might outweigh this change.

The role of CDTI is yet to be established. Its use may vary from simply monitoring to one of putting major responsibility in the cockpit for separation. A monitoring role would be the easiest to implement and would provide a valuable addition to cockpit information in giving the crew a quick reference for locating aircraft targets. The present system of advisories from traffic controllers is a crew attention diverter with flight deck eyes scanning to acquire a reported closeby aircraft. A spot of light on a plan view indicator to locate range and bearing of the target would be a big help in providing reassurance to the crew. Supplementary information on the dynamics of the situation could be obtained, i.e. altitude and speed via voice communications. In addition, a simple display could be useful in IFR conditions, for example, to inform a pilot, that he is overtaking an aircraft.

One of the problems with displaying CDTI data in the cockpit is the need for integration on the primary navigation instrument along with map, navigation, weather, obstacles, collision avoidance, and related information without cluttering the display and providing so many variables to assimilate that workload and attention demands reduce safety. Attention demands escalate rapidly as aircraft targets are increased.

One of the problems of moving additional responsibility for separation into the cockpit is concern about the accuracy of the information supplied under all geometric conditions. Sensors for CDTI data have not been defined. Both ground based and airborne based sensors have been mentioned as

candidates. Ground based systems have problems of accuracy on aircraft that are closely spaced at a distance from the ground sensor. The problem is equivalent to that of manipulating large numbers to get small differences. Small percentage changes in large numbers can make wide variations in the differential numbers. Additionally, the data on the ground must be transferred to the aircraft by data link. If DABS were used for the data link then the update rate would be limited by the number of users requiring information as a certain proportion of the traffic.

An airborne derived system, such as Full BCAS, would have an easier job of obtaining accurate data since the BCAS can interrogate nearby aircraft as frequently as required and the full BCAS-to-intruder geometry and signal-to-noise ratios are always good for the subjects of greatest interest-the closest aircraft. One of the negatives of an airborne derived system, such as Full BCAS, however, is its estimated high cost.

The definition of a viable CDTI system will require extensive simulation and flight testing to answer the many questions involved. As mentioned previously, even a simple approach of providing target location information for pilot monitoring would be a large step forward in cockpit information.

Weather - Weather information is included in the Navigation Group because it is of prime concern to air navigation. Weather information is accumulated from many sources - from briefings before a flight, from PIREPS, ATC, and company communications during a flight, from the on-board weather radar, and from any other sources found useful. Strategic weather information is used for general navigation planning purposes while the aircraft radar is used for tactical weather. Since strategic weather information is general and subject to vagaries of movements, the airborne weather radar is the best source of weather information and is the final arbiter of course changes.

Weather radars, however, require a great deal of interpretation of displays if aircraft are to stay clear of heavy turbulence. Radars detect the distribution of rainfall. They do not detect clouds or turbulence. By proper interpretation of rainfall gradients and shapes, movement speed, and the height of storms, a pilot can determine the distance to skirt a storm, or the altitude he must overfly a storm in order to keep out of heavy turbulence. In addition, STORMSCOPES, which detect lightning discharges, are useful for avoiding turbulence. Temperature gradient information is also helpful for detecting turbulence.

There is a need for storage and retrieval of information on weather ahead but out of range of the airborne weather radar. This could be in the form of alpha-numerics or in the form of weather maps. A convenient manual or automatic means for keeping this information updated needs to be considered.

Flexibility for display of airborne weather radar information is needed. Provisions for selectable display of radar data only or integrated as part of a navigation map display on the primary navigation instrument are depictable features. The map display of weather data provides the pilot additional information on the movement of weather cells relative to his ground track. With ground-referenced points on the map, the direction and

speed of weather movement can be determined.

Navigation/Flight Management Systems - Navigation today is most generally accomplished where nav aids are available by flying VOR radials in an autopilot heading mode with heading adjusted to average the VOR deviation. Distance is obtained from co-located DMEs or from some combination of nav aid bearings, and/or DME readings. The workload consists of selecting and tuning nav radios, identifying tuned stations by their identifiers, selecting VOR radials, observing deviations, adjusting heading, noting DME distances and TO-FROM indicators. This system works well and will continue in use through the end of the century.

Fuel and crew cost escalations, experienced and projected, together with increasing air traffic has generated a great deal of interest in increasing aircraft operating efficiencies. One of these concerns is more direct routing of flights than is provided by VOR airways. Even though distance savings may only be a small percentage of the total flight, fuel and time costs are so significant to airlines today that even small savings are worth pursuing.

Area Navigation (RNAV) systems provide the information a pilot needs for flying direct. Those supplying only lateral guidance are referred to as 2-D, those with vertical guidance added - 3-D, and those also providing time guidance - 4-D systems. RNAV computers operate with some combination of inertial, air data, VOR, DME, Omega, LORAN C, and precision approach (ILS) navigation sensors and possibly GPS and MLS in the future. Operating from stored flight plans which are defined by waypoints in terms of their locations along the flight path (2-D, 3-D, 4-D). VOR and DME radios are automatically tuned by the RNAV computer from stored information.

RNAV requires entering the flight plan into the computer. This may be done manually by entering through the Control/Display Unit (CDU) the latitude/longitude of the flight plan waypoints (2-D), plus waypoint altitude (3-D), plus scheduled time at waypoint (4-D). The flight plan may also be entered automatically from a tape loader or in the future by data link over the ACARS system. If sufficient computer storage is available on-board, an airline's entire route structure can be stored and a particular route obtained by selection through the CDU. The stored NAVAID radio data base must be updated periodically to keep the information current. This is generally done by use of a tape loader.

After ATC clearance for direct routing and after clearing the terminal area, with the RNAV system coupled to the autopilot. The navigation workload on the flight crew is eliminated as long as the original flight plan can be carried out. ATC requirements for separation, however, frequently require modifications to the flight plan. Weather also can require flight plan changes. These changes reintroduce a navigation workload since flight plan data may require modifications and the pilot must change the autopilot mode or manually fly the aircraft until a revised flight plan can be established. Similar interruption of automatic navigation can be expected when approaching a destination if there are any traffic problems. RNAV systems are still beneficial however, in terminal area landing situations in keeping track of location at all times, especially if the information is presented as map data on an electronic display.

An aircraft can be flown automatically or manually by means of pitch and roll steering commands from an area navigation system with the pilot handling the throttles. This was satisfactory when fuel and crew costs were a minor percentage of total operating costs. Cost considerations now make it prudent to extract greater efficiency from aircraft by use of performance computers. These computers take into account current operating conditions continuously and provide airspeed control by pitch and throttle commands to get proper performance for the operating mode selected. The interrelationship between navigation, aircraft performance, propulsion control, and fuel management has generated the Flight Management System Concept.

Flight Management computers require, in addition to navigation data, aircraft and engine performance and limit data to be stored in the computer. Crew data entry is required for weight and balance information plus applicable ATIS data such as temperature and wind. From this, the FMS computes takeoff data - V1, VR, V2 and flap retraction schedules. The FMS is operated by pilot selection of flight modes, plus selection of the desired option within modes - i.e. economy climb, maximum rate climb, etc. Planning data may be called up by the crew such as: climb distance/climb time for intercepts; fuel data such as fuel over destination at long range cruise; range/endurance data such as range/endurance to reserve level/dry tanks; and altitude data such as optimum cruise FL, or wind trade.

Coupling the FMS to automatic flight and automatic thrust control systems provides an integrated arrangement that removes some of the workload in the cockpit, particularly from the flight engineers position. The need to calculate performance parameter targets from handbook data, for example, is eliminated.

The addition of position/time control to a 3-D RNAV system converts it into a 4-D system. A 3-D system requires the addition of a time source plus software changes with navigation waypoints defined by horizontal coordinates, altitude, and planned time of arrival. The main objective of 4-D RNAV is precise control of flight time so that a landing slot time can be established with ATC prior to an aircraft's departure which can be met without in-flight delays. The goal is fuel conservation and improved scheduling. By coupling 4-D RNAV to flight controls and throttle systems, automatic navigation can be accomplished with time along the flight path under computer control.

The above scenario is an ideal at this time. There are no technical problems with precisely controlling an aircraft's time to fix points as this has already been demonstrated by Lockheed in an L-1011 flying between Palmdale, California and the Dallas/Ft. Worth, airport. The problem with realizing the many benefits of a 4-D capability lies in fitting the capability into the ATC system.

If ATC had only airlines and their fixed schedules to accommodate, the problem would be smaller than it is. There would still be random events to contend with such as equipment or other delays, emergencies, weather, and similar happenings that would take special handling. Further, all airline aircraft would have to be equipped with 4-D RNAV to realize maximum efficiency from the system.

The major problem, however, is created by the mixture of random traffic

not operating on pre-established schedules. Business, general aviation, and military aircraft must be accommodated by the ATC system.

It is expected that 4-D RNAV will gradually make its way into aircraft with new production aircraft offering this capability even though the benefits may not be realized for sometime. Once 4-D equipped aircraft are available, fitting into the ATC system can be started, working toward objectives of fuel conservation and improved scheduling.

Microwave Landing System (MLS) - The MLS is discussed in both the Flight Group and in this section. The emphasis here is on the horizontal situation information.

The MLS is a C-Band time-referenced scanning beam system designed to provide azimuth coverage of up to plus or minus 60 degrees and elevation coverage of 20 degrees with provisions for a co-located precision DME for distance information. The system also provides for back course and for flare guidance. The configuration of a particular installation will be determined by local needs. MLS also incorporates a basic and optional auxiliary data link channel. The basic data function contains station information. The auxiliary data functions have not been defined.

MLS is designed to accommodate straight-in approaches using the same procedures as for ILS, and segmented and curved approaches to the extended runway centerline.

The straight-in approach presents the least demand for cockpit information. Current electromechanical instruments should be satisfactory for displaying MLS information. A minimum MLS receiver, providing deviations from fixed approach angles would enable an MLS to be flown in the same manner as ILS.

More complex segmented and curved approaches will require a more advanced implementation. This resolves into how the approach paths are defined and implemented and the information needed by the pilots to monitor or perform these maneuvers.

There are an infinite number of approach paths which could be flown using MLS derived guidance information. It is assumed that because of noise abatement, obstacles, the requirement for orderly traffic flow, and the need for approach controllers to know what each aircraft is going to do that some standardization of permissible approaches will evolve as experience is gained with time. Approach paths could be selected by ground controllers and data linked via DABS or MLS to the aircraft, and inserted into a navigation computer by the pilot upon agreement; or, paths could be defined by the pilot through negotiations with approach control and inserted in his computer. These approach paths may be defined by waypoints with straight line segments, by a circular segment, or by a combination of these. Segmented approaches will require sufficient leg length to allow capture and settling on each leg with consideration of turning capability and passenger comfort. The airborne computer for MLS navigation may be a part of an MLS receiver, a special purpose computer, or the job may be done by an RNAV computer.

Because of its rapid adoption by the aviation community, the RNAV

approach is expected to predominate for use with MLS. RNAVS are set up for flying segmented waypoints with automatic switching and capture of each leg. The time of the next leg capture maneuver is dependent upon the aircraft speed and the angular relationship of the next leg to the current leg. Small angles require less time for capture. At the proper time, a roll command turns the aircraft on a circular arc segment to capture the new leg automatically prior to reaching the "TO" waypoint of the previous leg. Bank angles are generally limited for passenger comfort.

Since RNAV systems were not designed with MLS in mind, questions about their precision need to be raised. Individual designs need to be examined on their capture characteristics and suitability for the terminal environment. Bank limits might need to be altered for example. Accuracy of overall flight path control needs to be determined.

Provisions will be required for a changeover from the NAVAID sensors normally used by the RNAV system to the MLS sensors when this mode is selected. There are two mechanizations of RNAV systems in current use. One is based on great-circle navigation with waypoints defined in latitude and longitude coordinates and which uses a variety of sensors such as - VORTAC, DME, VOR, Omega, etc. for position updating. The other, which is more common in business aviation, operates on magnetic courses with waypoints defined by offset VORTAC coordinates. Any changes for these systems to operate in an MLS mode can probably be handled by modification of the software and provisions for getting MLS information into the computer.

At some point in the approach prior to reaching a herein undefined altitude, safety considerations would make it desirable for MLS signals to be coupled directly to the displays or flight control system if an autoland capability was in use to eliminate the complexity of RNAV hardware during the more critical phase of landing. It is expected that RNAV systems could deliver the aircraft to the straight-in part of the approach at a safe altitude before being removed from the control loop.

Special computer routines could be developed to increase compatibility of existing cockpit electromechanical flight director and HSI instrumentation with MLS curved approaches when MLS DME are available. Synthetic curved approach paths could be defined as segments of curves which would provide the equivalent dot deviation characteristics as a localizer would produce on a straight path at the same distance from the source.

The amount of cockpit information, however, can be considerably increased when electronic instruments are available. A map display on a horizontal situation indicator showing the desired flight path and that relationship of the aircraft to the flight path and the airport provides the pilot an easily assimilated picture of his horizontal situation. When flight path prediction points are projected on the display a short time ahead of the aircraft, a pilot gets added information on what his control inputs will do to his flight path in the next minute or so. Such predictive information is essential in both the navigation and flight instruments for flying descending curved approaches where all references are moving.

The adoption of segmented and curved MLS approaches must await a number of developments. ATC procedures must be developed for every installation and

meshed with present procedures. Criteria must be developed to define safe limits of operation for aircraft equipped with electromechanical instruments at one end of the scale through a variety of capabilities to the most advanced aircraft at the other end of the scale.

COMMUNICATIONS

Communications is an important part of the overall cockpit information flow, ATC clearances, maintenance of aircraft separation, metering and spacing, terrain and weather avoidance and similar information pertaining to air traffic control are conducted by communication exchanges between air traffic controllers and aircraft. Weather information is picked up in flight from company sources, air traffic controllers, flight service stations, other aircraft and any other sources available. Automated Terminal Information Service (ATIS) provides information on local weather conditions and airport data over communication links. Company communication channels are used to transfer operational and maintenance data. Flight crew intercommunications, communication with cabin attendants, and public address announcements are all part of the communications workload in the cockpit.

This discussion covers external and internal communication. The External Communications Section includes voice and data-link with the outside world, primarily ATC and company. The Internal Communications Section pertains to communication matters inside the aircraft.

External Communications

Until fairly recently, all communications between aircraft and the outside world were conducted over VHF, UHF and HF voice radio channels. A step forward was made by the introduction of the ARINC Communications and Reporting System (ACARS), a data link system that is rapidly gaining acceptance by the airlines. ACARS is used for company messages. It operates through the ARINC communications network.

A second two-way data link channel in the cockpit will be available when the Discrete Address Beacon System (DABS) with its associated data link function is deployed by the FAA in the ATC system and DABS transponders are installed for exchanging messages with the Air Traffic Control System.

There are other communication links to aircraft although not commonly thought of as such. NAVAIDS have identification and message capabilities. The MLS, for example, has an auxiliary data channel open for providing ground to air data. DMEs have the capacity for providing additional information such as their lat/long, altitude and "goodness" factors which would be useful for RNAV systems since this data would not have to be carried in airborne storage that requires periodic updating.

Data links which make possible air/ground/air computer-to-computer communication will increasingly take over some of the workload now handled by voice communication. This will relieve some of the communication problems encountered in congested areas, such as the Los Angeles Basin. Although more of the load will be shifted to data link, there will continue to be, for the foreseeable future, requirements for person-to-person voice communications to cover ad hoc situations even in a highly automated environment.

Voice Communications - The workload of voice communications with ATC is handled by the Captain and First Officer. The Second Officer or Flight Engineer generally handles company communications. The workload consists of frequency and radio set selection, establishing contact by identification of both ends of the link, transferring the message, and message acknowledgement.

A flight requires a great deal of communications with ATC. Clearances must be obtained for every move. Ground control must be contacted for clearance to start engines/pushback from the gate and for taxi. The tower must be contacted for takeoff clearance and departure control must give clearance shortly thereafter. The number of enroute ATC contacts required in flight is dependent upon the route and altitude. More contact is required for the lower altitudes than for the flight levels. Automated Terminal Information Service (ATIS) is tuned when approaching destination for information on the terminal and local meteorological conditions. Enroute control must be contacted when any amendments to the filed flight plan are desired. Traffic advisories, conflict avoidance guidance and weather information are sent over the ATC/aircraft communication links. Clearance to start descent/altitude clearances are obtained from control and the aircraft is metered to an outer fix. Approach control is contacted when approaching the destination for vectoring instructions and any other pertinent information for merging and spacing in the landing traffic flow. Next, the tower is contacted, followed by contact with ground control for instructions on taxi in.

These ATC contacts require a great deal of frequency selection and conversations during a flight and are a significant part of cockpit activity. It has been proposed that the DABS data link be used to automatically tune airborne radios for ATC voice communications. Once a flight is started, the hand off from controller to controller would automatically select in the aircraft the frequency required for each change of controller. It is believed that this arrangement would receive enthusiastic endorsement by the airlines. A study and service testing of remote tuning would be required to expose any problems in the concept, such as terrain and line of sight considerations as well as ATC coordination. Suitable last frequency recall may be required.

One approach to aircraft radio control is to centralize frequency selection/mode functions for all radios - both communication and navigation into integrated microprocessor controlled panels. This is in contrast to the current method of individual set controls.

An integrated control installation would consist of a panel each for the Captain and the First Officer. Communication between the controls and the equipment being controlled and communication between the control panels themselves is accomplished over digital data buses.

The centralized radio management concept provides a standardized means for selecting all radio frequencies and requires less console space than the individual control approach. This advantage has to be balanced against the advantage of having VOR/DME/ILS tuning on the glareshield adjacent to the automatic flight control mode selector such as is done on the L-1011 and other aircraft. A pilot can maintain awareness of his flight control mode

and guidance source in a head up mode when using these sensors. The communications and navigation frequencies are combined on the same panel with the integrated approach.

Automated Communications - The Discrete Address Beacon System (DABS) data link and the ARINC Communications and Reporting System (ACARS) provide additional channels for the flow of information to and from aircraft over digital links. The DABS link will be used for ATC communications and the ACARS is used for company communications.

Data links are most useful when used for computer-to-computer communication. Arguments for data links quickly fall apart when manual data entry demands get above the simple. This current limitation could be eliminated or minimized, however, if voice recognition becomes an acceptable means for data entry in aircraft.

DABS Data Link - The FAA is in the process of developing candidate uses of the DABS data link function. Some of these are as follows:

(1) Takeoff Clearance Confirmation - a backup to voice clearance for display in the cockpit as alpha-numeric information. Cockpit confusion occurs at times on the status of a clearance.

(2) Altitude Assignment Confirmation - a backup to voice delivered altitude assignments. This is a safety enhancement by having altitude assignments displayed in the cockpit rather than depending upon crew memory or the possibility of misunderstanding.

(3) Minimum Safe Altitude Warning - a backup to voice delivered warnings. This warning is delivered whenever an aircraft drops below a minimum safe altitude for an area and continues to be delivered until the aircraft regains a safe altitude.

(4) Enhanced Terminal Information Service (ETIS) - This is a replacement for the current Automatic Terminal Information Service (ATIS). ATIS messages are voice recorded and updated hourly or more often by human beings. ETIS is a digital system with automatic sensors providing meteorological data at airports.

The DABS data link format is being developed to allow ETIS to be requested by individual data item selection in the cockpit from a menu or by selection of the entire ETIS message. Provisions are also being made for automatic update of ETIS data at pilot option.

ETIS is an improvement in data transfer efficiency over the present voice recorded ATIS. Currently, pilots must listen to an entire recording and pick out the particular data desired. Since voice recordings are updated periodically by ground personnel, there is always the possibility of stale information on the local situation. This has generated the procedure of identifying the ATIS received by phonetic letter designation when contacting ATC in case the information needs updating.

(5) Weather Information - The data link provides an alternate means for getting weather information that is now received by voice radio

communications. Weather information may be requested over the DABS data link. Some of the services planned are: surface observations, terminal forecasts, PIREPS, hazardous weather advisories, weather radar maps, and winds aloft. Weather services require automation to effectively use the data link for this purpose.

Operation of the weather service requires data entry by the pilot of the location identification and extent of weather coverage desired and menu selection of the weather products. The information delivered to the aircraft is alpha-numeric or map information depending upon selection.

(6) Metering and Spacing Advisories (M&S) - M&S information is now transferred to an aircraft by voice communication from a controller. Pilots are given headings, altitudes, and speeds in order to be merged and spaced in trail for landing.

The development of a computer-aided M&S capability in the ATC system opens the possibility for data linking guidance advisories directly to each aircraft over the DABS data link. It is expected that an operational scenario would have the data displayed in alpha-numerics to the pilot on his EHSI or other suitable display for manual flying. For automatic flight the same display would be used and, upon concurrence with the advisory, a pilot would insert the basic information into his flight management system by a single switch actuation. The flight management system would then adjust the aircraft's pitch, roll, and thrust status to automatically maneuver to the advisory situation.

It is expected that data link vectoring will be implemented initially in the same format as is now used for voice - i.e. heading/altitude/speed changes. In the long term when 4-D navigation is an operational reality, the data format may be changed to waypoint/time coordinates. It is still expected, however, that this information would not be used by direct routing to the airborne computer but, rather, would be presented to the pilot for concurrence and computer entry.

(7) Clearance Delivery - This function has been proposed as a DABS data link service. This interchange of information between the aircraft and ATC is important and the data link can provide this exchange with less chance for error or misunderstanding. A pilot must compare the ATC clearance against his filed flight plan and, if different, decide whether or not he can comply. Occasionally ATC must amend a proposed plan. During this interchange with voice communications possibilities are opened for misunderstanding. The busy radio spectrum, other aircraft with similar call signs and misinterpretation of what is said, all add to the possibility of error. Data link provides precise information. If negotiations are required, a reversion to voice can be resorted to with the final product in alpha-numerics displayed in the cockpit. The use of data link will help unload voice channels. Clearance delivery is mostly automatic with airlines and handled directly with ARTC Centers.

(8) Downlink of Aircraft Information - One of the applications of DABS data link being considered is the downlink of aircraft information. Information derived from airborne sensors is a potential source of valuable data to add to the ground-derived air traffic control information. Some of

the information might be obtained by specific request from the ground while other event-type data might be transmitted automatically at the time of the event and included in a downlink message at the next downlink message slot available.

Aircraft with navigation computers aboard have position, ground track, ground speed and wind speed and direction available which could be formatted automatically for downlinking to the ground upon request. Similarly maneuvering data such as bank angle and airspeed, could be made available for automatic transmission via DABS. Fuel remaining information could be made available for a holding situation.

To illustrate some of the uses of this data, aircraft descending in terminal areas that are equipped for on-board wind information could be requested periodically to transmit wind speed and direction while descending to obtain wind profiles for profile descents. This information would be useful in the future when on-board 4-D navigation is used in achieving desired time to fixes. Good wind data below the aircraft could be uplinked over DABS and inserted into the navigation computer prior to starting the descent. Similarly, enroute aircraft at various flight levels could supply winds aloft data upon request from the ground and this information could be made available to other aircraft upon their request via DABS. A more favorable wind at another altitude is valuable cockpit information for fuel conservation.

Airspeed and bank angle information, properly filtered to remove normal control transients induced by turbulence, could be automatically transmitted over DABS when an aircraft starts a turn to provide predictive information for ground control computers. Aircraft under automatic control could transmit course airspeed and altitude changes as they are selected.

ARINC Communications Addressing and Reporting System (ACARS) - ACARS is a data link system used for company communications via the ARINC network. The airborne system modulates a standard VHF voice radio set with information transferred at a 2400 bit/second rate. ARINC is currently developing a system for the HF spectrum.

Prior to ACARS all information transfer between airlines' aircraft and their operations/maintenance offices had to be done using voice transmissions. ACARS has been accepted rapidly because of its flexibility and increased efficiency. A message which can be transmitted in less than 0.5 second by data link would take 10-60 seconds to handle by voice.

The initial application of the ACARS was for automatic transmission of "out/off/on/in" time, or 000I, reports. When engines are started or shutdown, "out" and "in" reports are transmitted automatically. Landing gear sensors are used to initiate "off" and "on" reports. 000I reports include the aircraft and crew identification. This information is used for logging airframe, engine, and crew time. These data may be automatically fed into an airlines' computers for keeping a running log on each aircraft.

Other applications of ACARS are limited only by imagination and money. Preflight information for an aircraft's weight and balance, trim setting, passenger load, etc. can be delivered automatically from a company's dispatch

computer via ACARS with the information conveyed to the crew by an on-board printer. Connecting ACARS to a flight management system opens up many possibilities for exploiting the company computer to flight management computer link. Temperature and surface wind information could be inserted without human intervention for calculating takeoff data. In flight, winds aloft information could be put into the flight management system for wind trade computations to notify the crew when a more efficient altitude was available. Fuel information could be obtained from the aircraft at any time. Information on flight progress could be tracked by company computers. An ACARS interface with an aircraft's AIDS would provide an automatic link with maintenance.

ACARS also has a selective calling service for establishing voice contact from a company to an aircraft and vice versa. A dispatcher's message alerts the flight crew and displays the frequency to use for voice contact. This frequency can automatically be tuned by ACARS. For aircraft to company or other voice communications, a 2-digit code is used and the phone patch is currently made by an ARINC operator. Direct automatic dialing is planned for the near future so that any number can be obtained by 2-digit codes for frequently used calls or 10-digit numbers using area codes for less frequently used numbers.

ACARS controls have provisions for alpha-numeric data entry and display function keys for data identification and instructions to the computer, and annunciators pertaining to the housekeeping functions of operating the data link. Maximum advantage of ACARS potential is had when data is automatically acquired and composed into messages with minimum requirements for crew data entry. When pilot input requirements are anything but minor, the usefulness of using any data link quickly disappears in favor of person-to-person contact by voice.

Internal Communications

Internal communications is defined as the transfer of information to/from and within the cockpit without the use of radio frequency transmissions. These transfers are accomplished currently by speech or by written material.

Written material is either of a general reference nature or is developed for a specific flight. Reference information includes items such as airways charts, approach and departure charts, and handbook data of aircraft performance. Specific information developed for each flight consists of items such as the flight plan which contains the route definition, airport data such as runway in use, wind, temperature, etc., performance targets for climb, cruise, and descent, time of flight and other information; weather forecasts; aircraft weight and balance data; aircraft and engine log data entries; and similar written documentation that is unique to a particular flight.

Most of the requirements for written material will disappear for future aircraft. All of an airlines routes may be stored in computer memory with a specific route selected from a menu or routes may be inserted in navigation computers directly from dispatch computers using an ACARS data link. Aircraft weight and balance information can be transferred to a flight

management computer by the same means. Flight management systems have aircraft performance curves in memory. With weight and balance information together with airport data i.e. temperature, wind, etc, the computer provides EPR setting, V1, VR, V2. Weather forecasts can be sent to the aircraft over data link at any time. These may be displayed as text, as weather maps, or printed out by cockpit printers. Approach and departure charts can be stored in computer memory and called up for display as required for a particular flight.

The flexibility of memory and the progress made and expected in the future in ease of data entry in computers all indicate greater usage of this approach in the future to replace printed material. On board printers can be used to obtain printed material when desired. A printer can also be used as another display in the cockpit to copy routine data link messages - ATIS for example when it is made available for data link transmission.

One of the most troublesome areas of cockpit information is that of communications between members of a flight crew. The subject frequently surfaces in accident investigations where communication of vital knowledge held by a crew member did not get to the captain either by not being articulated, being misunderstood, or by the captain filtering it out - not recognizing its significance. The failures to communicate have not been attributed to technical design or failure but rather to human failure. It is not believed that the answers, if there are any, will be found in design as long as the human being participates in the control loop. Additional automation of functions offers hope.

CAUTION, WARNING, MONITORING AND CHECKLIST FUNCTIONS

The functions of caution, warning, monitoring and automated checklist prompting have many similar requirements. As they are considered in detail their distinctions become blurred and the need for an integrated approach in keeping with the rest of the flight station definition becomes apparent.

All of these functions require information on aircraft state obtained from various outputs of other systems and either require or could benefit from flight phase definition. Their outputs are primarily text with prioritization necessary to define the output mode required to properly compete for crew attention relative to other systems and functions.

In addition to text output on various displays with the use of color, letter size and blinking, audible output in the form of tones or voice may be used to either gain attention or ease workload. Many questions remain to be resolved regarding their proper integration into the flight station. Together, however, they probably will have the greatest impact on both workload and safety of the foreseeable cockpit changes.

In the past caution-warning information has been annunciated by various lights and illuminated legends scattered around the cockpit as well as a large collection on a centrally located, fixed indication caution panel. Although there are many disadvantages to the old approach, a point in its favor is that an identification cue is provided by the location of the indication. This cue is eliminated when a centrally located CRT display is used. A crew member is now forced to read the legend before getting any

indication of its significance, thereby increasing workload during what may already be a stressful situation.

Several options are available which can improve this situation while retaining the advantages of the new system. Prioritizing cautions, advisories and warnings by flight phase, suppressing less significant annunciations during critical flight phases and color coding those presented should reduce needless distraction and spread workload. Providing annunciation of exceptionally critical warnings on or adjacent to the primary flight instrument and using voice output would further reduce scan requirements at such times.

Monitoring is the process of observing a situation, windowing the observation, and reacting if limits are exceeded. Unfortunately, during critical periods, many observations must be made in a short time, resulting in less attention to each. Furthermore, reaction to one out of tolerance condition may inhibit further monitoring until the first condition is resolved. Even more common is the failure to note a discrepancy when readings have been stable for a long period, resulting in reduced vigilance. The extremes of monitoring requirements are exemplified by two periods of flight in particular, takeoff roll before V_L speed, and high altitude cruise.

Although many tests and checks have been performed during preflight and taxi out, an aircraft moving into takeoff position is still, to a large extent, an unknown entity to the flight crew. The surfaces have been cycled, valves and pumps operated, and engine parameters have stabilized to acceptable values. Nevertheless, takeoff is one of the most stressful aspects of normal aircraft operation. Aircraft weight is at the maximum for that trip. Engines are operated at near maximum pressure ratio even though temperatures have just begun to stabilize. Vibration levels during takeoff roll normally exceed those encountered in flight in both amplitude and frequency. Wind speed and direction is unpredictable and highly variable at ground level. Control surfaces and landing gear may be experiencing operational loads for the first time since maintenance. It may well be the first time the crew has flown this particular aircraft and in fact, the first time they have flown together.

The decision speed, V_L , is the first critical speed point. Prior to this point the aircraft can, supposedly, be stopped in the runway length remaining. Beyond V_L , the aircraft must fly to avoid potential disaster. Considering these factors it should not be surprising that the period between throttle advance and V_L encompasses the peak of monitoring activity.

During this period of approximately thirty seconds the pilot advances the throttles to obtain takeoff EPR and verifies stable and acceptable values for engine speeds and temperature. The brakes are released and the start of roll time is noted. As the aircraft accelerates, direction must first be maintained by means of nose wheel steering with the rudder gradually gaining effect. The wings must be kept level during this time in spite of gust effects and cross winds. Runway ice can aggravate the situation, allowing the airplane to literally be blown off the runway, if traction is not sufficient. Slush on the runway, dragging brakes, insufficient power or premature rotation can result in reduced acceleration. Even more subtle is

the effect of a decreasing headwind. An airplane flies by airspeed, but inertia dominates the acceleration equation at the low speeds of takeoff. For these reasons airspeed acceleration is a critical variable at takeoff.

As the pilot attends to the details of control, the First/Second Officer is monitoring airspeed, acceleration, engine performance and the annunciator panel. Critical speeds are called out as they occur.

The flight engineer scans his panel verifying systems operation and notes the takeoff time for the log.

Depending on aircraft performance, weight, temperature, altitude and runway length V_L may coincide with the rotation speed or differ by many knots. In any case, below V_L the objective of the crew is to abort the takeoff if critical problems are encountered. After V_L they must make the best of what they have.

During this period the premium is on rapidity and accuracy of monitoring. If a discrepancy is noted it must be quickly correlated with other observations and a decision made to either continue on or perhaps subject the passengers and the aircraft to the trauma of an emergency stop.

During long range cruise the airplane and the crew normally settle into a steady state. Throttles are retarded to cruise EPR, engine and system parameters stabilize. The autopilot maintains altitude, airspeed and course. The crew maintains a scan of the instruments and the outside, visibility permitting. Although time is certainly available, no longer are instruments and indicator lights observed in the darting, rapidly repeated sequence used during takeoff. In fact, if a distraction occurs, for example ARTCC advises of traffic which is not immediately located by the flight crew, considerable time may lapse between instrument scans while the entire crew turns its attention to the area of concern. Incidents are on record where a crew allowed a plane to crash while their attention was attracted to some relatively minor malfunction.

In neither of these examples is the crew well suited for the task required of them. Whereas man is far superior at inductive reasoning and spontaneous solutions to unpredicted problems, machines have the advantages where rapid, accurate conclusions must be drawn from predeterminable combinations of factors. Furthermore, the machine will do this ad infinitum with no loss of attention from boredom or distraction.

As a result of expanding computational capability, more monitoring functions are being assigned to computers. The result is that crew members can focus their attention on the designated out of tolerance conditions almost as soon as they occur and without overlooking subsequent discrepancies in the process of resolving the first.

It should be observed that the discrepancies found during monitoring have consequences which are of varying significance by flight phase, but their priorities also vary by flight phase. Loss of altitude at 400 feet is far more serious than loss of pressurization. The reverse is true at 41,000 feet. As a matter of fact, the mere annunciation of an insignificant malfunction at a critical moment could conceivably precipitate a disaster

through distraction. As a result of such things, the ARINC characteristic 726 goes to great effort to prioritize annunciations by flight phase and to designate which should be suppressed and which announced and by what method during takeoff and landing.

Closely related to monitoring functions are checklist activities and to a large extent, each supports the other. Performing checklist functions accounts for a considerable portion of the efforts of the flight engineer and the copilot particularly. Because of the importance given to checklists, the weaknesses of the traditional approach and the ease of providing alternative means with the excess capability of raster scan CRT's, the major avionics companies are offering checklist options with their weather radar systems. The present systems are rather simplistic, but do provide convenient storage of checklist data and most offer the ability to skip an item and then be reminded of it later. By integrating the checklist system with the monitoring system an even more powerful tool is created. Prior to the initiation of a subsequent flight phase, the automatic monitoring system can verify checklist accomplishment or annunciate open items. As the flight phase progresses, activities may be prompted if not done as scheduled. An example might be resetting the barometric reference during descent as 18,000 is penetrated. In more cases the monitoring system, itself, can ascertain when a checklist item is accomplished, making check entry unnecessary.

IV - CURRENT COCKPIT WORKLOAD SUMMARY

A summary of cockpit workload by flight phase is contained in this section. The aircraft is not equipped with navigation or flight management computers.

TAXI OUT

The current workload is predominantly maneuvering the aircraft, the taxi checklist and communications along with external visual scanning. P1 or P2 gets clearance and taxi instructions from the ground controller. Instructions must either be remembered by the flight crew or written on notes.

P1 is controlling the throttle, brakes, and steering. S/O updates the gross weight and P2/S/O finalize the takeoff data which is checked by P1. Takeoff data includes calculations for V1, VR, V2 and flap retraction schedule. S/O reads the checklist, sets his panels, P1/P2 respond as required. Flaps/slats, trim, and controls checks are accomplished to ready the aircraft for flight. Flight attendants are notified of pending takeoff.

During taxi the ground controller hands off the aircraft to the tower controller. P2 retunes his radio and P1 contacts the tower for lineup instructions. P1 and other crew members receive tower instruction clear to line up and hold, or clear for departure.

TAKEOFF

Upon receiving tower clearance, P1 steers the aircraft, aligns it with the runway centerline, and holds. Any remaining checklist items are completed. P1 is headup and commands "Takeoff Thrust". P2 applies thrust, monitoring engines instruments for EPR set and stable, RPM's in limits and stable, oil press/temp, in limits, fuel flow normal hydraulic pressure within limits, all warning communications out. P2 or S/O verifies takeoff thrust. P1 releases brakes, steers, maintains wings level and keeps aircraft aligned with runway. Takeoff power is usually available in about 5 seconds. During the takeoff roll (15-20 SEC) the cockpit workload is heavy. P1 is loaded controlling the aircraft. P2 and S/O are supporting by monitoring engine, airspeed, and other instruments. P2 notes that acceleration is normal (e.g. 80 kts, in 22 sec) - notifies P1 at rudder effective speed. Prior to V1, "thought processes" are alert to stop. P2 announces "V1". P1 now mentally transitions to airborne emergency procedures. P2 announces VR. P1 pulls back column to "unstuck" the aircraft and achieve takeoff pitch attitude. S/O monitors engine instruments and P2 monitors flight instruments. P2 announces "Positive Rate" of climb and retracts landing gear. P2 calls "V2", P1 holds V2 until clear of obstacles, noise abatement or 400 ft. S/O now usually transitions to his station and P2 usually transitions to headup, checks for traffic right and left and handles communications. Tower transmits any final vectoring instructions and hands off to departure control. P1 retards throttles to climb power. P2 retunes comm. radio and contacts departure control for instructions. P1 usually selects heading and engages flight

director. Then P1 usually selects vertical speed (VS) mode and desired altitude, e.g. 3000-7000 feet. P2 retracts flaps per schedules on callouts from P1 (FMS).

After clearing the immediate airport area and workload associated with initial departure decreases, P1 calls for the after takeoff/climb checklist. The S/O reads and all crew members execute.

CLIMB

The aircraft continues climb and accelerating to intercept the initial VOR radial. P2 or P1 selects and tune VOR stations per the flight plan. P1 adjusts pitch/throttles to maintain 250 knots below 10,000 feet. At an early point in the flight P1 usually engages the autopilot and divides his attention between instrument monitoring and outside visual scanning. P2's primary role is outside scanning for traffic and ATC communications confirming arrival at checkpoints, confirming and entering altitude clearances, etc. At 10,000 feet P1 levels the aircraft and accelerates to his desired climb speed. P1 then pitches the aircraft up to maintain the desired climb speed. P2 retunes his comm. radio after handoff to ARTCC. Retuning is required for each enroute handoff. P1 and P2 reset their baro altimeters to standard reference when passing through 18,000 feet.

The S/O is busy logging times, monitoring instruments, and reporting particulars on flight progress, needed maintenance, fuel, etc. over the company communications link.

During adverse weather, P1/P2 operate the weather radar to avoid thunderstorms about their flight path. Concentrated attention is required to evaluate intensity. ATC advisories, PIREPS, and any other source of weather intelligence are used to establish a picture of the weather ahead. The flying pilot maneuvers the aircraft on diversionary courses as required to keep out of heavy turbulence.

CRUISE

As the aircraft nears the assigned cruise altitude, which has been preselected on the altitude select panel, an alert notifies the crew. The autopilot noses the aircraft over and captures the altitude. P2 or P1 notifies ATC of reaching assigned altitude and estimates arrival time at next checkpoint. The S/O computes cruise mach and the flying pilot adjusts thrust to accelerate or decelerate to desired cruise mach. Cruise flight is almost always in mach hold unless the route length is too short to climb to mach altitude.

Cruise is generally a relaxed phase of flight except in bad weather or when malfunctions develop. VORTAC station and course selections by P1 or P2 guide the aircraft and the flight is under autopilot control. Monitoring of instruments is a continuous activity as is external visual scanning particularly when traffic advisories are received. On long cruise flights it may be desirable to step to a higher altitude to conserve fuel. P1 or P2 obtains clearances from ATC, selects the new altitude on the altitude select panel, adjusts throttles, climbs and capture new altitude. S/O computes cruise mach and P1 or P2 adjusts power to hold.

There is a flow of communications with ATC between P1 or P2 during the flight. Checkpoint crossings and next checkpoint ETA are reported. ATC may temporarily divert the aircraft from its course for conflicting traffic. Messages are passed from other aircraft. There is requesting and advising on winds aloft. Information is received and transmitted on weather, clear air turbulence etc. Traffic information outside of radar surveillance areas is transmitted and received.

The S/O is similarly busy with company communications reporting checkpoint crossings/ETA's, needed maintenance, fuel usage, needed fuel, telephone contacts with offices etc.

The flight crew gets involved from time to time in identifying malfunctions, troubleshooting, and isolation of failures.

DESCENT

Toward the end of cruise, the S/O does an alternate airfield reserve fuel calculation. P1 or P2 receives and copies ATIS information for his destination airport. P1 or P2 calculates beginning of descent point based on location of desired end of descent point, weight, speed, temperature, winds. Descent planning is often done from crew experience and rules of thumb but this is expected to change for fuel conservation reasons. P₁/P₂ review approach procedures as needed.

The S/O computes landing data. P1 calls for the descent checklist. The S/O reads and all three participate. The S/O sets airport altitude into his ECS and monitors temperature/pressure sets fuel and electrical panels for landing. P2 checks hydraulic system etc. P1 or P2 requests and obtains ATC clearance to begin descent.

P1 selects desired vertical speed and sets in "cleared to" altitude. At beginning of descent, P1 engages "VS" mode of autopilot and retards the throttles to idle and the aircraft begins descent. P1 or P2 contacts ATC to notify of leaving cruise altitude for cleared altitude. P1 and P2 continue to request further altitude clearances for enough in advance so that, hopefully, the aircraft never has to level off. P2 resets his altitude select panel as each clearance is obtained. P1 and P2 set their instrument bugs for VREF and go-around EPR. P1/P2 report arriving/leaving cleared altitudes and overflight of checkpoints. P1/P2 observe traffic, weather, etc. P1/P2 reset their altimeters to field altimeter baro at 18,000 feet. Flight is handed off from ARTCC to TRACON and P1 or P2 retune comm. radio for approach control, VOR's and radials are selected as required throughout the flight for course guidance and navigation. The aircraft is leveled off and slowed to 250 knots by 10,000 ft altitude in the terminal control area.

APPROACH/LAND

P1 executes vectoring instruction maintaining speed and altitude schedules. P1 calls for flaps per extension schedule and P2 operates the flap, P1 calls for the approach/land checklist. The S/O reads and all crew members respond to checklist items. The S/O communicates with his company for gate assignment. P2 tunes the VOR/LOC and arms the "ILS" mode on the flight director selector panels. P1 flies the aircraft to and intercepts the

localizer - followed by guideslope intercept. Around the outer marker control is passed from approach control to the tower and P2 retunes his comm. radio to the tower frequency. P1 calls for "gear" and P2 lowers the landing gear.

Weather and turbulence are major factors in determining cockpit workload in this critical phase of flight. When neither are present, landings are made routinely with the flying pilot operating head up. With marginal visual condition in choppy weather, workload is considerably increased. The flying pilot is loaded just maintaining control of the aircraft. The non-flying pilot has major responsibilities for maintaining altitude alertness and speed control. One procedure has P1 flying on instruments. At some point on final P2 starts dividing his attention between his altitude and speed responsibilities and outside scanning for runway visual cues. P2 is responsible for altitude callouts e.g. "100 feet above decision height (DH)". Prior to DH P2 must determine if runway information, in his judgement, is sufficient to continue the landing. If so, he advises P1 - "runway in sight." P1 goes headup and P2 reverts to instruments. P2 calls out "DH" and, if P1 agrees that a landing can be made, continues the landing. P2 follows the control movements of P1 mentally prepared to carry out a go-around maneuver if required.

Assuming a landing is made P1 retards the throttles, flares the aircraft, and maintains alignment on the runway. P1 calls for reverse thrust as required - P2 complies. P2 calls "80 knots". Instructions are received from the tower controller advising exit turnoff and handing off control to the ground controller. P2 selects ground-control frequency and receives taxi instructions which the flight crew must mentally file or make notes, if complicated.

TAXI-IN/SHUTDOWN

The workload in this phase is caused primarily by the after landing checklist and the shutdown checklist; steering, thrust, and braking control of the aircraft; and external visual scanning. It is common practice to shutdown one or more engines during taxi to conserve fuel.

P1 controls steering, thrust, and braking. P1 calls for after landing checklist. This mainly involves flap retraction, zeroing trim, and shutting down systems. The S/O reads the checklist and all crew members respond. P1 and P2 maintain vigilance outside for other aircraft/obstacles.

Some busy airports maintain ground traffic control towers at the airport which are operated by the airlines. These towers are contacted for further taxi instructions. Some airports require towing to gates so tug operators must be contacted.

P1 maneuvers the aircraft to his gate position for final guidance by the ground crew. After ground power is supplied, engines are shutdown. P1 calls for the shutdown checklist and all crew members execute shutdown of systems. If this station terminates a flight, additional shutdown of equipment is required.

The S/O completes his log recordings.

V - ADVANCED INTEGRATED AIRCRAFT

CHARACTERISTICS

The Advanced Integrated Aircraft incorporates several technologies projected to be practical about 1990. All of the technologies involved are currently in use, but have not yet been developed to the level required for commercial aviation applications. The capabilities of global information exchange, distributed processing, very large memory capacity, redefinable display functions and digital communications combined with design emphasis on modern control theory and human factors analysis will be exploited to improve the efficiency of both the aircraft and the crew, as well as the interrelation between the two. There is little doubt that the concepts involved will be in widespread aircraft use by the end of this decade, however, the details of utilization are still quite flexible.

Probably the most significant technology to be available to the aircraft industry in the next decade will be the high speed, multiple access, serial data bus. By making practical virtually total integration, high levels of redundancy and an extremely flexible system design, this data bus will change the basic approach to aircraft systems design and development. Multiple data usage, parameter monitoring, malfunction detection, redundant sources and displays will be greatly facilitated. Aircraft wiring weight will be greatly reduced as will modification and conversion difficulties, since all black boxes have the same power and bus connections. Distributed processing techniques will permit the use of multiple, lower cost computers to achieve high computational rates, greater redundancy and failure independence. Large memory capacities will enable much information such as performance curves, approach procedures, standard company routes, navigation aid data, checklists and even maps to be stored away as processing reference data or for crew usage. Electronic displays will provide pictorial and text information in formats optimized for the flight situation. In most cases, the need for frequently used information will be anticipated by the system, but other data may be selected manually as required. Display failure should be relatively rare, but here again system flexibility will allow lower priority functions on nearby displays to be replaced with the more critical information. Digital data links will provide fast, unambiguous means of exchanging information with the ground, reducing communications channel loading, misunderstanding and, cockpit workload. Modern control theory is providing better tools with which to develop the control laws required for improved flight director and autoflight systems to deal with the challenges of higher traffic density, curved approaches, reduced separation, landings and windshear. Human factors will play a large role in determining the automation levels, display formats, control requirements and annunciation methods to best employ these new technologies.

It should again be stressed that the implications of the multiple access data bus, distributed processing, large memory capacity, variable display formats and data link communications are far different from those of previous avionics technologies. Although a conventional cockpit could be designed to incorporate these technologies the result would fall far short of the

potential of the integrated cockpit and probably of the isolated systems cockpit also. It is neither lack of technological capability nor the lack of acceptance of potential advantage that prevents these methods from being put into use today, instead it is the lack of knowledge of what is really desired and needed.

The envisioned Advanced Integrated Flight Station consists of Captain, First Officer and Second Officer positions, each of which is provided with large, dual electronic displays in a side by side arrangement. A flight control display and a navigation display for the Captain and the First Officer and two system control displays for the Second Officer. Two additional displays are centered, one above the other, on the panel between the pilots, primarily for engine monitoring and caution-warning functions. A ninth display slopes between the caution warning panel and the console. This display is a multifunctional device similar to the system control displays of the second officer. It provides checklist and systems control functions as well as weather, map and CDTI in conjunction with the text input/output panels which are on either side. Each of these panels consists of a text display with display labeled switches and a full alpha-numeric keyset. They are used independently to input, review and modify FMS flight plan data, retrieve stored information, to provide DABS and ACARS text input and display capability and to facilitate manual interface with any component on the data bus. The Second Officer is also provided with an identical panel. Two communications management panels located aft of the low profile throttle quadrants provide radio channel selection and display. A printer is located between the Communications Management Panels and is available to all systems on the data bus.

The center console layout provides a clear view of the multifunction display and easy access to the Communications Management Panels and printer for the Second Officer. The Second Officer's chair slides back and swivels about to a centered position to facilitate support of the two pilots.

In addition to the voice warning outputs, provisions will be available for optional voice input and output for a number of selection, data entry and information retrieval functions. In many cases this feature may eliminate the need for text input/output medium.

FLIGHT CONTROLS

The primary flight controls of the Advanced Integrated Aircraft consist of coupled center mounted control sticks and conventional rudder pedals which provide limited nose wheel steering. Manual throttles, trim, flap, landing gear and speed brake controls are placed in the forward console area between the pilots, reachable from either position. Electrical controls for these functions are provided on or adjacent to the control sticks, but are logically interlocked to preclude improper actuation. The use of the electrically actuated interfaces provides a high degree of interaction between the crew and the aircraft. Control prompts can be received through the displays which can be sanctioned by switch actuation, allowing the system to carry out the action suggested. The center console controls allow total override when emergency situations or unforeseen circumstances require that normal constraints be ignored. This approach provides a high degree of automation with the associated precision and repeatability while maintaining

pilot awareness.

FLIGHT DISPLAY

The flight control display provides a path predictor format optimized for the flight phase. Sufficient information will normally be provided for flight control without reference to other displays. By combining the functions of the present attitude director, horizontal situation, airspeed, altimeter, vertical velocity and critical warnings into one display, the visual workload will be reduced. Cognitive workloads will be reduced by using improved symbology, color and more direct information tailored to the flight phase and task in work.

Critical warnings resulting from onboard system failures or configuration will be prioritized according to flight phase and presented in the lower portion of the flight display consistent with distraction criteria based on flight phase.

Critical warning information originating from the Discrete Address Beacon System (DABS) data link and from onboard system such as the Beacon Collision Avoidance System (BCAS) and the Ground Proximity Warning System (GPWS) will be incorporated into the Flight Display consistent with their effect on flight path control. Automatic Traffic Advisory and Resolution Service (ATARS) advisories, insofar as they pose no immediate threat, will be presented on the navigation display. Aircraft entering an alert volume surrounding this aircraft but with a non-threatening trajectory would evoke a proximate aircraft alert symbol on the flight display. This would be a strip along the display border defining the direction of the intruder and implying that a maneuver to that direction would be hazardous.

Aircraft on a course projected to enter the threat volume of the aircraft within one minute would evoke a resolution symbol. The resolution symbol would be a vector on the display indicating the avoidance maneuver direction. Color would be used to imply urgency.

In either case the critical warning block at the bottom of the display would clarify the annunciation.

The BCAS system would require a similar approach with exceptions made for the lack of left-right maneuver information in all but the most elaborate systems. The DABS Minimum Safe Altitude Warning (MSAW) service and GPWS will also make use of the vector symbol to imply the pull up maneuver.

Basic attitude information will, of course, be provided throughout flight. Supplementary information may, however, change considerably as required by each flight phase. During preflight and even taxi out this display as well as the others may be used for systems status and controls checkout functions. Prior to the beginning of takeoff roll, the Flight Management System will calculate the takeoff data and as the appropriate speeds are reached prompt the pilot accordingly. Simultaneously, acceleration will be monitored to assist in the go-no go decision. Such information is conveniently displayed as a "rising thermometer" indication of airspeed on the left of the display with labeled "bugs" to indicate V_1 and VR and the scheduled speed for the elapsed time or runway distance. Automatic

monitoring of engine, surface positions and other critical parameters will reduce scan requirements during takeoff roll. Significant deviations prior to the decision speed will be annunciated on the flight display to allow an early abort if necessary. After V_1 speed and until somewhat stabilized flight is achieved, perhaps V_2 and 400 feet altitude, warning significance will be weighed against the distraction effect to determine the annunciation method.

After lift off, landing gear and flap retraction will be monitored against the FMS generated schedule and the actions prompted if necessary. The flight path display will indicate the optimum climb angle, the stall margin and track angle, as well as pitch, bank, altitude and airspeed. Clearances and crossing altitudes and airspeeds, and preloaded flight plan data will be used to drive the display symbology to provide climb out guidance or monitoring. By matching the flight path predictor, acceleration vector and target information, altitude and time schedules may be achieved with low workloads.

Climbing through 18,000 feet will result in automatic reset of the altimeter references to standard sea level pressure. As altitude increases, the airspeed scale will reflect the narrowing region between stall and mach buffet. Waypoint crossings will be annunciated and appropriate guidance or monitoring information provided to maintain altitude, schedule and course, either automatically or manually. Deviations may be entered through the Flight Management System or the Navigation Display either by manual input or by acknowledging uplinked messages. These changes will then be used to drive the flight display for guidance and monitoring. Profile descent guidance will be handled similarly with the Flight Management System determining the necessary tilt point, pitch and throttle settings to meet time, fuel and metering point constraints, and presenting reference marks on the flight display. Passage through 18,000 feet will result in a prompt to reset the altimeter references to local sea level pressure.

Intersection crossing altitudes, clearances and vectors will be processed by the Flight Management System and the appropriate guidance commands presented on the flight display to assist in interception of the landing path.

Initialization of the approach phase will result in computation and presentation of landing data and optimization of the display for the approach guidance system to be used. Flap and landing gear extension will be monitored against the landing data schedule and prompts displayed as necessary. Airspeed and ground speed data will be processed for windshear detection. Distraction effects will again be considered in determining warning annunciation methods during the final seconds of flight.

NAVIGATION GROUP

The Navigation Group Display is a large high-resolution electronic color device adjacent to the Flight Group Display and in a dual installation. The display is used to integrate navigation and other information which is closely associated with navigation. This instrument should provide the pilot with all of the information needed to safely navigate an aircraft from origin to destination.

Basic Navigation

Basic navigation information will normally come from flight management systems. A reversionary capability is needed, however, to display information directly from the navigation sensors in case of flight management system failure.

Track-Up or Heading Up Display - The normal format for basic navigation is a map type track-up or heading up display containing flight plan waypoints and course lines between waypoints. Identification of waypoints appear for 10 seconds adjacent to each waypoint symbol upon pilot selection. A digital readout at the top of the display provides track or heading azimuth with identification of source - magnetic or true. An azimuth segment is shown across the top of the display. Also displayed at all times are time and distance to the active waypoint and ground speed. A course select symbol, which moves along the azimuth segment at the top of the display, indicates the next course. If off scale, a digital readout of the next course appears at the end of the scale. A drift angle symbol is displayed on the azimuth segment. Wind speed and direction is a callup option and remains on the indicator until deselection.

A breakoff symbol appears on the display, accompanied by an aural alert, prior to reaching a waypoint to indicate the point for start of intercept of the next course line.

Since vertical navigation is a part of the overall navigation solution, altitude and altitude guidance information appear on the display. Altitude guidance is accommodated by a dedicated vertical deviation display on the right side of the navigation indicator. The altitude of waypoints is depicted on waypoint identifier labels.

A trackball and cursor are used for insertion of changes to waypoints to eliminate the need for manual entry of new waypoint coordinates. A readout of cursor coordinates is presented adjacent to the cursor when it is in use.

Weather is presented on the navigation display at pilot option. The location of storms cells relative to the course and their speed of movement of can be determined.

Range marks are permanently displayed along the track line by short line segments and the scale in use is displayed at the bottom of the display. Range rings may be displayed at any time at pilot option.

A time/position symbol is displayed on the course line to indicate flight progress against schedule when 4-D navigation is in use.

The location of NAVAIDS and obstacles are selectable options for display on the navigation indicator. Obstacles and their altitudes automatically appear on the display when the aircraft is at altitudes that make the information important.

Standard Terminal Arrivals (STARS) are computer stored data and are called up on demand. Courses, NAVAIDS and intersections appear on the map display as these items come within range of the selected map scale. Bearings

to NAVAIDS can be called up by laying the cursor on the NAVAID symbol if present on the map or by entering the identifier in the flight management system to call up a NAVAID off the scale. Bearings are presented on the map by a direction line and a digital readout of bearing. Airport symbology appears on the map when within range.

Radar vectoring to final approach course is received from ATC over the DABS data link in terms of waypoint coordinates, altitude, and speed advisories. These are viewed by the pilot on the map display and upon agreement and acknowledgement, are automatically entered as waypoints, altitude, and speed commands in the flight management system. This scenario assumes that ATC has implemented automatic metering and spacing and vectoring is under ground computer control for aircraft properly equipped.

Prior to reaching an MLS intercept point, the MLS path is presented via DABS for pilot review on the navigation display and acknowledgement. Upon acceptance, these data points are automatically entered into the flight management system. The navigation continues under area navigation control until the aircraft is aligned with the MLS azimuth centerline where control passes to the MLS.

Compass Rose Display - An alternate to the map display is provided by a conventional compass rose. Electronic symbology is used to duplicate the information appearing on a conventional electromechanical display plus some additional useful features that were not available on the electromechanical instrument.

A readout at the top of the lubber line provides digital heading information. The source of this information is identified as magnetic or true. A vertical deviation display appears on the right side of this format.

Two bearing pointer segments are available for VOR or ADF bearing information. Each pointer identifies, by means of an attached symbol, the sensor being used for the information.

When operating in a VORTAC navigation mode, particulars on the No. 1 and No. 2 VOR/DME sets are displayed at the bottom of the display. The set supplying information to the course arrow is identified along with the frequency to which it is tuned. The VORTAC station's 3-letter identifier is displayed through decoding of the DME identifier. The DME distance is shown. The same block of information on the VORTAC tuned on the No. 2 set is also shown.

Display of ATARS/Full BCAS/CDTI

Information from the above systems should be integrated into the Navigation Display. Because the information is so closely associated with navigation and flight control, putting it on a primary flight instrument is a logical approach. A problem of scale, however, is created by ATARS, for example. This system must provide information both enroute and in terminal areas. ATARS is a ground-based automatic system that operates in small scale and transmits advisories only when aircraft are a few miles proximate. It is normal to have a navigation map scaled to long ranges when enroute. Since a

pilot may have no prior knowledge when other aircraft are close, proximate or conflict alert information may be buried in his own aircraft symbol. The aircraft symbol is intentionally normally made large so as to always be distinguishable from other information on the map. An aural alert provides information so that a pilot can switch his display to a small scale.

The use of a separate indicator for ATARS in Advanced Integrated Aircraft is not attractive since this approach would provide flight critical information on yet a third indicator and, instead of restricting pilot attention to a primary flight instrument with support from a navigation instrument, a third critical display would be introduced. This does not seem to be the best way to go. It appears better to provide a cockpit alert when short range information is present from ATARS so that a pilot may select a short range scale.

The display of ATARS/BCAS/CDTI data will require relocation of ownship symbol on the map display as used for navigation from the bottom center of the display to 1/3 up from the bottom for a track up mode or centered for a north-up presentation. The 1/3 up movement is required in order to present information on aircraft to the rear. The centered aircraft symbol is more suitable for north-up displays.

There is much development work yet to be done on displaying information from the subject systems. What data is displayed continuously to the pilot, what is made selectable, and what present candidates will not be used, has yet to be determined. The objective is to present the essential information in a straightforward manner without cluttering the display.

Information from the above sources will all be presented on the Navigation Group display. It is certain that range, bearing, and altitude information on surrounding aircraft must be presented. Bearing and range can be readily accommodated on the plan position indicator, but conveying altitude information in an intuitive manner is difficult. It is believed that color will prove the most useful for coding altitude information. The remaining information such as track, velocity, control status, aircraft capability, threat advisory, etc. are undefined at this time as to how the information on each should be presented. A combination of symbols, coding, and pilot selected information options should permit the transfer of essential information without excessive display cluttering - at least, permitting the pilot to control the level of clutter. Some automated safeguards will be required to notify the pilots through the combined alerting system when deselected data is needed or becoming critical, e.g. CDTI data is needed for M&S, CAS data, weather data, etc.

Planning Mode Display - A planning mode is included in the navigation group so that the indicator not in active use for navigation can support flight planning. This is an off-line function having a variety of uses.

Look-ahead on the present flight plan is available for retrieval. Particulars on runways and airport data are provided on demand. NAVAID and waypoint information can be retrieved and presented. An alternate flight plan or a diversion from present plan can be developed. Once developed and verified, the plan can be substituted for the present plan after ATC clearance is obtained.

COMMUNICATIONS

The communications requirement in the cockpit is one of managing on-board facilities and transferring information to and from the flight crew. Currently, cockpit workload, because of being restricted to voice communications, is significant. Computers and data links provide opportunities for greater automation and increased efficiencies in the communications function.

Voice communications workload is mainly comprised of frequency selection and the attention demands of establishing contact, message delivery, and acknowledgement. Information transfer rate is low and personal involvement is high. Data links deliver information at higher rates and personal involvement is low if the application of data link is proper.

Voice Communications

One approach to integration is the current one of consolidating all radio controls, both communications and navigation, into a single panel that is microprocessor controlled. An aircraft complement consists of two data entry/status display panels. The system is normally operated with the Captain's panel directly controlling the No. 1 radios and the No. 2 radios through the First Officer's panel and vice versa for the First Officer controlling the No. 1 radios. In case of a failure, a standby data bus is enabled to allow control of all radios from the working unit.

Frequency selection is accomplished by selecting the set to be tuned, keying in the frequency, verifying and entering the results. The frequency status of any or all radios can be determined by viewing the panel.

The centralized approach is an improvement since controls are standardized and cockpit control clutter is reduced. Manual frequency selection is still required for voice radios, however, so cockpit workload is not significantly altered. Navigation radios are already automatically selected and tuned by flight management systems (FMS). The FMS operates through the centralized panel when auto-tuning is selected, and frequency status of the nav, radios are shown at all time. The next step is to automate tuning of the voice radios.

When automatic tuning service is available from the FAA over the DABS data link, this function can be mechanized in the cockpit. The tuning message is addressed to the aircraft at the time of handoff between air traffic controllers. An alert and annunciation appears on the radio panel in the cockpit and the First Officer tunes his radio by actuating the data entry key. By selecting the "AUTO" mode for ATC communication, the data entry requirement is not required and communication radios will be tuned in the same manner as the FMS tunes the nav. radios.

The option for automatic tuning for voice communication with company operations is already available on the ARINC Communications Addressing and Reporting System (ACARS) when voice contact is desired between the company and its aircraft. Normally, this radio will be tuned to the ACARS frequency. It can be auto-tuned when the frequency message is received for voice contact. The radio is then returned to the ACARS frequency after the

voice contact is completed.

An alternative to ground tuning of airborne radios is offered by voice recognition equipment. This field is advancing rapidly in capabilities and may well find many applications in aircraft. The recognition of numerics as is used in radio frequency selection is a simple application. One of the present drawbacks, the requirements for training recognition equipment to recognize the user's voice, is expected to be eliminated or minimized in the future as more is learned about the elements of speech. Frequency selection by voice would consist of operating a "LISTEN" switch, enunciating each number, verifying the results, commanding "ENTER", and deactivating the "LISTEN" switch.

Data Link Communications

Both the Discrete Address Beacon System (DABS) data link and the ARINC Communications Addressing and Reporting System (ACARS) are considered in this section. These systems are interfaced with the Flight Management System (FMS) and are operated through the FMS. The DABS data link is used for automated communications with the ATC system and ACARS is used for automated company communications. Some of the messages sent over these links are completely automated while others require some crew attention.

The DABS Data Link - The DABS data link is interfaced with the FMS computer. Current designs of flight management systems centralize a large number of functions. This has raised some concern about software complexity and the loss of capability after failures. It is believed that the current centralized information processing approach will be changed in the future in favor of distributed processing. Data buses provide a great deal of freedom. It is believed that the current serial ARINC broadcast data buses which are uni-directional will be changed in the future to higher speed half duplex buses. It is envisioned that many computers will be used in the future processing individual sensor information and having access to common data buses. Users of this information would extract their information from the bus. Bus architecture is such that alternate paths are available to ensure that the data is transferred in case of bus problems. There are several types of bus protocols to choose from: Centralized Command/Response, Distributed Command/Response, and Contention. Centralized Command/Response employs a central bus controller that elicits responses from individual units on the bus in sequential order. Distributed Command/Response performs the same sequencing only control of the bus is shifted between several bus controllers. Contention controlled buses operate by individual controllers contending for bus control when a bus is not in use according to their assigned priority. Each of these bus control methods have advantages and disadvantages and the best is determined by the particular application.

It is therefore believed that the FMS of the future will be a distributed system and the DABS data link tie-in is a logical choice. All types of aircraft sensor data and display capability can be accessed through the FMS. Control of DABS data link can be accomplished through the FMS control terminal.

The nature of DABS uplinked messages determines how the information is passed to the flight crew. Routine clearances, altitude assignments, and

similar information is passed to the flight crew by routing to dedicated flat panel displays which are installed in close proximity to each of the Flight Group Displays (FGD). ATARS advisories on proximate aircraft are routed to each Navigation Group Display (NGD). ATARS threat advisories are routed to each FGD and NGD and along with alert signaling. A conflict resolution advisory is routed to each FGD. Minimum safe altitude warnings are routed to each FGD. Clearance delivery is routed to the cockpit printer.

Crew requests over DABS for weather, ETIS, etc. is done through the FMS data terminal. This is accomplished by calling from computer storage menus of the data desired. Crew data entry to locate the desired weather area is required, for example, and also the choice of map display on the NGD or alpha-numeric printout on the printer. Similarly any or all of the ETIS data can be obtained for output on the printer. Automatic updates of ETIS can be requested.

Since the FMS has access to a great deal of aircraft performance and navigation information, these data can be made available through software upon requests from ATC. For information that needs to be transmitted in near real-time from the aircraft - turning information or turbulence information, for example, these exchanges can be made automatically without the need for flight crew intervention in the loop. It is expected that other messages requiring crew data entry will in the main, be handled by a callup of standard messages containing blanks for variable data that is filled in through the keyboard by the operator.

Data link housekeeping functions such as: data link armed indication inability to communicate, etc., appear on the FMS terminal.

The ACARS Data Link - The ACARS data link is also interfaced with and controlled through the Flight Management System.

There is a great deal of commonality between the DABS data link and ACARS. Both receive messages from ground computers. Neither can transmit at any time. DABS must await an interrogation from the ground in order to transmit while ACARS depends upon determining that the ACARS channel is clear before transmitting. Therefore both have a transmit message arming requirement. Both systems have automatic message capabilities. Both systems have provisions for flight crew originated messages. All information exchanges must be computer verified and technically acknowledged.

The DABS interface with the flight crew is primarily through its dedicated message display and the flight and navigation instruments for transfer of air traffic control information. DABS also has need of a printer to record weather, ETIS, etc. information.

The ACARS primary interface with the flight crew is through a printer for company communication and a modest requirement for display of alpha-numeric text. Integration with the flight management system permits company access to navigation displays for map display of alternate route recommendations or other navigation information.

Both data links have requirements for pilot input of alpha-numeric data. The FMS keyboard is proposed to satisfy these requirements. Both data

links have requirements for function keys for data identification and for instructions. Whether these functions should be handled by multifunction keys or by dedicated keys can only be determined by detailed design tradeoffs which are beyond the scope of this study.

CAUTION, WARNING, MONITORING AND CHECKLIST SYSTEM

The CWMC system automates several functions which are dependent on flight phase and aircraft system status. The system facilities include a color caution-warning display, a space for several lines of text at the bottom of each flight display for critical warnings, voice input/output capability and several audible warning devices.

Cautions and warnings are prioritized and annunciated in accordance with predefined rules which consider relative importance and distraction effects with respect to flight phase. Regardless of flight phase or altitude, all warnings and malfunctions are annunciated on the caution-warning display and their initial presentation is accompanied by a chime sound. The flight display space is used for extremely critical warnings during high workload, limited scan periods. The audible warning devices are used to gain attention when the situation warrants it. The primary purpose of voice output is to gain explicitness without increasing the memory load required for audible warnings. Display labeled switches adjacent to each CRT line provide the capability to interact with Caution-Warning annunciations.

The checklist function is activated prior to each flight phase transition to compare the aircraft state against the stored checklist data for that phase. The crew is prompted on out-of-configuration items and queried on items which do not lend themselves to monitoring. Display labeled switches provide the capability to respond to queries, to move items to the end of the list or to override items in exceptional cases. Prompted actions are removed from the list automatically as they are accomplished. A significant aspect of the checklist function as opposed to the manual checklist is its ability to prompt actions during the execution of a flight phase rather than only at the beginning. Examples are the prompting of flap retraction by predetermined schedule and resetting of the barometric reference when passing through 18,000 feet. The checklist function primarily uses the CWMC display for outputs, however, some prompts which are related to aircraft control are made through the flight display. The system provides the option of voice interface to reduce visual workload when outside scanning requirements are high.

The monitoring function reduces scan requirements and increases sensitivity to parameter departures from pre-set values. The system serves to some extent as a failure monitor although this is not its primary intent. Many system parameters either normally operate around calculable values or are set to some specified value. Examples are the altitude clearance level or engine instrument readings. The monitoring system reduces workload by pointing out the deviations while ignoring in-tolerance values. The approach essentially applies the "Management by Exception" philosophy to the aircraft flight station. The development of the multiple access serial data bus will greatly increase the practicality of the monitoring system by making data acquisition much less of a problem. By listening to the normal interchange of data between other systems on the bus the monitor can acquire information

with little added overhead. Considerable intelligence is built into the monitor so that both its judgement criteria and its response to deviations changes with flight phase and situation criticality. Items deemed non-critical during high workload periods would only be presented on the monitor display. Serious deviations would result in annunciations which would be escalated to warnings if not promptly acknowledged.

SYSTEMS DISPLAY AND CONTROL PANELS

The systems display and control panels are large electronic displays with display labeled switches and touch panel capability which provide reversionary control and indication facilities for electrical, hydraulic, environmental and fuel systems. System diagrams appear in a somewhat abbreviated form made practical by the use of digital indications and color designation of flow paths and control points. Dual panels are provided for reasons of capacity and redundancy. Each panel has independent computation, storage, symbol generation and data bus interface facilities. Each panel tracks and may present any system's data at anytime without regard to the other panel. In addition to the basic system display modes, system test, monitoring and checklist functions also are available through the panels.

TEXT INPUT/OUTPUT

Normally, text input and output are accomplished by means of the text I/O panels which are provided for each crew member. The panels consist of a 16 line by 32 character transfective liquid crystal display and full alpha numeric keyset, both backlighted by electroluminescent panels for night visibility. Display labeled switches are provided at either end of each line for menu option selection. These panels are actually terminals which communicate with the aircraft distributed computer system through the serial data bus. Because of their flat panel design they may be unlatched from their normal positions and latched onto the users chair arm or hand held to facilitate usage by right handed First Officers or left handed Pilots. The panels are primarily used to interface with the Flight Management System and the DABS and ACARS data links. They may also be used to command the printer to print the contents of a text display or to monitor the outputs of another system, DABS for instance.

The printer is a particularly useful tool in the Integrated Flight Station. As a result of the data bus it is available as an output to all aircraft systems. Its major function is monitoring the DABS and ACARS data links, however, it may be used to monitor any system outputs, parameter values or computation results. An example might be the Flight Management System Takeoff and Landing Data. Large type output could be selected for this function for easier reading by the pilots.

CREW DUTIES

Taxi Out

During taxi out the primary task of P1 will, as in the past, be scanning and maneuvering the aircraft, unless some form of automatic buried wire guidance system were to be adopted. The main responsibilities of P2 will continue to be communications, monitoring, checklist performance and

scanning. However, he should be able to provide more scanning support as a result of a considerable reduction in checklist and monitoring activity. S/O duties should also be reduced because of the reduced checklist and monitoring requirements and the automation of takeoff computation. Unless the company provides a data link or other means of information transfer, some information will still have to be manually entered, tests will require activation and results must be monitored.

Takeoff

The automated takeoff checklist will prompt items and verify configuration conformity when requested. Takeoff clearance will be confirmed through a DABS data link indication, and thrust applied. The takeoff parameters will be displayed on the text I/O panel and also as "bugs" on the Flight Displays. As the aircraft begins to accelerate, the rate will be monitored automatically as will the other significant performance indications. P1 will scan outside and steer the aircraft if auto flight is not engaged. P2 will monitor the flight display and be alert for monitor annunciations as well as for the VI and VR prompts which he annunciates. Possible options for this task are headup display prompts or synthetic voice prompts. P2 will provide redundant scanning and monitoring.

In normal operation, the crew functions are virtually unchanged from the past. However, if a discrepancy should occur it would be dealt with more effectively since the crew attention can be directed toward outside scanning which is difficult to automate and toward scanning fewer inside points for highlighted annunciations. Checklist errors would be eliminated as well as monitoring oversights.

Climb

P1 or the autopilot will rotate the aircraft and shortly after a positive climb rate is indicated the gear must be raised or a prompt will ensue. Similarly the monitor system will expect the flaps to be retracted according to the schedule indicated on the flight display or prompts will be issued accordingly. The ACARS link is used to automatically notify the company of lift off.

During the foreseeable future it appears necessary that the flight crew and the departure controller will be required to verbally interact to guide the aircraft clear of terminal area traffic for eventual handoff to the enroute controller. Hopefully, the DABS data link will eventually be able to provide altitude, heading and airspeed clearances in the terminal area as well as voice communication channel frequencies in a form that could be automatically displayed in the cockpit and when acknowledged by the flight crew, directly entered into the appropriate aircraft system. This would reduce misunderstandings, oversights, radio channel clutter and workload.

Once clear of obstacles and in stabilized flight, the items presented by the after takeoff/checklist would be accomplished to clear the display. During climb the monitoring system will maintain a vigilant watch over engine and flight system parameters, immediately bringing deviations to the attention of the crew. This feature will allow more emphasis to be placed on outside scanning under VMC or more attention given to other sources of

traffic information such as ATARS, BCAS or CDTI and to weather radar under IFR conditions. The Second Officer would be able to assist in these functions and in communications switching under normal circumstances as a result of his reduced workload and because of the attention given to seating and console layout.

After handoff to the enroute controller, altitude clearances can be received directly through the DABS data link. These are acknowledged by a button press and automatically inserted into the Flight Management System. As the aircraft passes through 18,000 feet the altimeter reference is automatically set to standard sea level barometric pressure.

The Integrated Flight Station would be less susceptible than human operators to blunders and oversights. More time will be available for weather and traffic watch due to automated monitoring. The Second Officer's role may change somewhat for this reason.

Cruise

Upon arriving at the assigned cruise altitude the aircraft would capture the altitude, alert the crew and could notify ATC through the DABS data link. Cruise EPR would be computed and set and the cruise checklist displayed. After accomplishing the checklist, winds aloft and weather data updates might be requested via DABS data link with printout designated for the destination or points enroute. The Navigation System would provide direct routing and automatically select the optimum Nav Aids along the way. Changes in ATC altitude clearances and eventually perhaps communications frequencies would be uplinked as required. These would be acknowledged by the crew and automatically input to the computers. Altitude changes would result in reoptimization of thrust settings by FMS. DABS weather updates frequently would allow unpleasant weather to be well skirted, ATC, fuel and schedule permitting. Weather radar would automatically alert the crew to high density weather cells on the flight path. The Captain could identify a deviation path on his navigation display using the track ball controlled cursor, store the new flight plan waypoints temporarily with the touch of a button and downlink them to ATC for clearance. On receiving clearance, another button press would activate the revised flight plan in the Flight Management System. The ACARs data link would be used to automatically inform the company of flight progress and new estimated arrival time.

About one hundred and fifty miles out preparations are begun for descent. Enhanced Terminal Information Service (ETIS) is requested for the destination using DABS and received on the printer. The Captain requests the destination Standard Arrival Route (STAR) on the multifunction display and contacts ATC to verify the destination outer fix. The End of Descent point is determined and, based on altitude and winds aloft data, the optimum Beginning of Descent point computed. If this is acceptable to ATC, it is entered into the flight plan. Clearance is received to the fix point altitude.

Normally, cruise is not a high workload flight phase and because of this, attentiveness may suffer. Auto-monitoring of systems may be of special importance as a result. Fuel conservation and anticipated ATC metering procedures may provide more tasks to be accomplished just prior to descent,

however. The exact and convenient nature of data link communications between computer system as well as onboard computational power would facilitate these activities so that workloads remain manageable.

Descent

Shortly before the Beginning of Descent, the Descent Checklist is executed. At the "Tilt" point the throttles are automatically retarded and the aircraft gently nosed over by the autopilot. ATC is informed that descent is underway and given the time to arrival over fix. The Second Officer requests and receives gate assignment information through ACARS on the printer. As the aircraft passes through 18,000 feet, the pilots are prompted to reset their altimeter references. This is done by auto-entering the latest ETIS value. The Second Officer requests CDTI on the Multifunction Display to assist in locating traffic even though conditions may be VFR.

The aircraft passes over the outer fix on time, on altitude and on speed. The voice communication frequency is switched by the Second Officer to the approach control frequency when requested by ATC.

Here again, auto-monitoring will usually allow the Second Officer to directly support the pilots in scanning and communications. As a result they may apply more attention to traffic, weather and flight path considerations.

Approach

As the Captain and First Officer monitor the flight path and maintain instrument and outside scans, the Second Officer manages the communications frequency selection and requests the MLS approach path from Approach Control. The path designation is received and entered into the Flight Management System allowing the path to be retrieved from memory. When requested, it appears as an overlay on the Navigation Display for each pilot. The approach controller provides clearance directly to the intercept point. The First Officer uses his track ball to slew a cursor on his Navigation Display to the intercept point and enters it into the FMS. The aircraft banks smoothly to the new track. As the aircraft symbol approaches the MLS path on the display, the First Officer selects "MLS". The Second Officer requests the landing and go-around data from FMS. The data appears on the Captain's and First Officer's Text I/O panel and as "bugs" on the Flight Display velocity scales. The Second Officer requests the pre-landing checklist and accomplishes the open items. As airspeed, altitude and distance to the runway diminish, the First Officer is prompted to extend flaps and gear by the Flight Display. The Captain monitors the autoland approach or flies the predictor symbol on the head up or head down Flight Display down the approach path and through flare.

During the very high workload period associated with terminal area navigation, the monitoring and computational workload reductions will allow transferral of some communications and data request effort to the Second Officer. This will allow both pilots to concentrate more on flight control tasks.

VI - INTERMEDIATE AIRCRAFT

This section contains a description of the Intermediate aircraft including a crew duty summary.

CHARACTERISTICS

The Intermediate Aircraft is characterized by extensive use of digital technology and the introduction of color electronic displays for flight control, navigation, systems and annunciation purposes. These applications, however, generally emulate conventional approaches in both systems design and presentation format. The ARINC 429 bus does not provide the global information exchange available with the multiple access bus system, the best known current representative of which is the MIL-STD-1553. Even though the 429 structure severely limits programmable data path modification, it does permit software modification of what data is sent over its predefined paths. The electronic displays also are quite adaptable to new formats and are capable of handling new information within the bounds of screen size and clutter effects.

Probably the most significant aspect of these aircraft is the incorporation of a Flight Management System which, in varying degrees, encompasses the functions of performance optimization, navigation, navigation aid tuning and data link communications interface. As a result of the access to aircraft and environment state data, prestored data, display facilities and potentially DABS and ACARS data link interface, the FMS may perform considerable data integration to substantially reduce crew workload.

The raster scan color weather radar display provides the attractive possibility of expansion to a multifunction role. Potential applications include cockpit display of traffic information and weather map data for remote locations.

The inclusion of a printer on many aircraft may also serve to reduce display requirements and to reduce crew workload by minimizing note taking of ATC and company instructions, malfunction data and weather information. In many situations a printout may serve as a cheap substitute for both computer memory and display capacity.

As a result of anticipation of advanced systems such as DABS and MLS as well as the adaptable nature of the Flight Management System and the format flexibility of the electronic displays, the Intermediate Aircraft should fit into the future air traffic environment with little difficulty.

FLIGHT CONTROL DISPLAY

The flight control display functions for the Intermediate Aircraft are implemented with electromechanical devices for altitude/mach, altitude and vertical speed indications and a color CRT display for attitude and guidance information. Backup capability is provided in the form of a barometric airspeed indicator and altimeter and an electromechanical artificial horizon

for pitch and bank data.

Anticipation of the changes to be made to the operating environment and the flexible nature of the CRT displays provided will allow the flight control display portion of this cockpit to be adapted gracefully to the new systems being introduced. As far as flight control functions are concerned, the EADI may be reprogrammed to provide symbology to support ATARS and BCAS resolution functions and the MSAW command with no impact on normal operation of the display. This presumes that system operation will be reliable enough that false alarms will be rare. In the event of an imminent disaster the avoidance data would have priority over most of the display data justifying considerable freedom of formatting if necessary.

The Microwave Landing System presents only a slightly more difficult problem in that the incorporation of a more sophisticated control law set and presentation would make curved approach tracking easier. The flight path display concepts are appropriate and readily adaptable to the Intermediate Aircraft display system. In addition to facilitating MLS approaches the flight path display will provide benefits in other flight regimes especially those involving vertical navigation and windshear considerations.

NAVIGATION GROUP CHANGES

The Intermediate Aircraft is defined as one incorporating ARINC 700 series digital technology. It is equipped with flight management systems and electronic flight instruments having more or less conventional formats. Although not currently incorporated, provisions for adding 4-D RNAV and MLS are made in ARINC Characteristic 702 as growth options. It is assumed that the Intermediate Aircraft has these items already incorporated.

A method of integrating ATARS, BCAS, and CDTI functions into the cockpit is to use the processing and control capabilities of the FMS and display the information on the electronic flight instruments (ADI and HSI). ATARS messages derived from ground sensors utilize the DABS data link for transmission while BCAS information is air-derived. Both of these functions in the aircraft are contained in the DABS ATC transponder. ATARS and BCAS information is processed in the transponder, formatted, and delivered on ARINC 429 serial digital data buses. Communications with the FMS is conducted over 429 data buses.

ATARS proximate aircraft and threat advisory information is displayed on the electronic horizontal situation indicator (EHSI) in a map mode. When ATARS is used, the aircraft symbol on the EHSI is relocated from the bottom of the display to 1/3 up from the bottom. An alert, used for pilot notification to select short range map scale, is triggered by any ATARS message. Resolution advisory information is presented by suitable symbology on the electronic ADI (EADI) for direction maneuvers and limits.

Active BCAS information is presented on the EADI as "fly up - fly down" command symbology.

The source of Cockpit Display of Traffic Information (CDTI) data has not been decided at this time. It is assumed that the information, when available, will be on a 429 data bus for coupling into an FMS port. CDTI

information may be displayed on the EHSI. A means to select or eliminate CDTI information on the display should be available. Also, the extent of CDTI coverage (range/altitude band) should also be a function that is pilot-selected.

DABS DATA LINK COMMUNICATION

Tactical messages, minimum safe altitude warnings, and extended length messages are communicated via the DABS data link.

An electronic flat panel, such as LCD technology, is suggested for tactical message display in the cockpit. These panels can be mounted on the Captain's and First Officer's instrument panels. Lack of depth requirements make these panels useable in locations that are unuseable for other instruments because of depth limitations. The display is self contained with driver and ARINC 429 bus receiver. A 429 bus interconnects the displays with the DABS transponder.

Minimum Safe Altitude Warning (MSAW) can be delivered through the flight warning computer system. Supplementary voice annunciation of the warning is an option.

The need for extended length messages over DABS is created by requirements for terminal, weather, and other information which cannot be handled in the 56 bit tactical message format. Messages are originated in the aircraft through a menu selection process and entry of data to identify the data desired.

The DABS communication link is integrated through the Flight Management System. Menus are stored in the Flight Management Computer (FMC). The Control Display Unit (CDU) interfaces with the DABS transponder only through the FMC and data is transferred over ARINC 429 data bases.

Information requests are developed using the CDU for call up of menus and inserting data to specify what information is wanted and where it is located. The message is routed to the DABS transponder and armed to be transmitted at the first opportunity. The "ARMED" indication is removed when the message is transmitted. The return message is routed to the ACARS Management Unit over a 429 bus for printout on the ACARS printer. The message may also be viewed on the CDU at pilot option.

CREW DUTIES

Taxi Out

The duties of each of the crew members, during taxi out, will remain virtually unchanged in the Intermediate Aircraft. The Second Officer's takeoff and landing data computation task will be eliminated by the Flight Management System which will compute the data directly, once factors such as aircraft weight, runway length and temperature are provided. Improvements in monitoring, self test and panel layout will also reduce the taxi-out checks required for each of the crew members. Storage of checklists in the Flight Management system will allow a limited degree of automation, but any workload decrease will probably be offset by the inconvenience of calling up and

reading from the display.

Takeoff

The takeoff checklist will be somewhat simplified by automatic checks but will remain a significant requirement. DABS data link will provide an unambiguous indication of takeoff clearance. The centralized caution-warning panel of this aircraft and auto-monitoring will reduce the takeoff roll scan requirement and improve abort condition response time. V_1 and VR prompts from the FMS could be provided through either a head up or a head down display to reduce scan requirements.

Climb

Little actual workload change will be noted during climbout as a result of the Intermediate Aircraft's systems. Flap retraction schedules and landing gear retraction prompts are easily implemented through the FMS. The FMS will also make practical a semi-automated checklist. Altitude clearance, vectors and communications channel selection will be manual, although the aircraft's technology would support the automation easily if it were available through DABS. ATARS and BCAS functions will be effectively implemented through the Flight and Navigation Displays. CDTI could utilize the color raster scan weather radar indicator. The FMS will make possible quick determination of performance capabilities and optimum settings. Frequently, the automatic monitoring system will permit the second officer to absorb the task of communication frequency switching. After handoff to enroute control, altitude clearances may be data linked up for display and entry.

Cruise

After capturing the cruise altitude, the FMS would cause the autothrottle system to select the optimum cruise EPR. After accomplishing the cruise checklist the crew workload would be quite low if weather and traffic were light. Otherwise DABS services might be used to keep track of weather ahead and to obtain terminal information for diversion consideration. Stored Flight Plans could be displayed as route maps on one of the EHSIs for example. Near the end of cruise the Descent Checklist would be accomplished. Prior to descent, the descent profile would be negotiated with ATC based on FMS calculations for minimum fuel usage, and the Beginning of Descent point established.

The Flight Management System, the DABS data link and automatic monitoring should maintain workloads at a reasonable level even in diversion and profile descent situations. The major tasks during cruise flight will normally be traffic and weather scanning, ATC channel selection and preparation for descent.

Descent

The aircraft accomplishes profile descent under autopilot control with the crew monitoring systems, scanning outside for traffic and weather cells, and interacting with ATC communications. During descent the local ETIS may be requested through DABS, and the Second Officer may contact the company for

arrival information through ACARS. At 18,000 feet the crew will be alerted to enter the local barometric reference pressure. Assuming clearances are received for each altitude in time, a continuous descent is possible to the level of the metering fix with enough space to allow the aircraft to decelerate to the desired speed before crossing the fix point.

Approach

After crossing the fix point the First Officer contacts approach control for instructions. Clearance to a lower altitude is received along with a vector to the MLS intercept point. As the intercept point is neared the First Officer arms the MLS mode. The MLS path parameters are extracted from the auxiliary data block of the MLS signal and stored in the MLS processor. Capture occurs as the intercept point is approached. The FMS now displays a flap and gear extension schedule which may also be presented as prompts on the EADI or HUD if desired. As the Captain monitors the flight path the First Officer extends the flaps and gear as the runway approaches. The captain takes control as touchdown occurs.

VII - ELECTROMECHANICAL AIRCRAFT

This section contains a description of the Electromechanical Aircraft.

CHARACTERISTICS

Systems integration in the Electromechanical aircraft is primarily the responsibility of the flight crew. The systems function independently and seldom utilize common inputs or outputs. The information exchange that does occur between components is invariant in path and function and that between crew and aircraft passes through dedicated displays and controls. As a result, the information of new systems requires new hardware, new wiring and, perhaps of even more concern, additional space. Since display locations were optimized for the original functions when the aircraft was designed, it is not likely that ideal locations are available for added functions. Similarly crew tasks allocated before the introduction of new equipment may have to be reconsidered to prevent workload saturation under some circumstances afterward.

In some cases the update of existing systems to later technology may provide multiple advantages. An example is the conversion to raster scan, color weather radar which can provide a flexible, multifunction, text and graphics display in addition to an enhanced radar function.

Another possibility, now becoming practical, is the use of a combination of liquid crystal and electroluminescent techniques of light emitting diode display technologies to provide flat panel text and simple graphics displays. These approaches have the advantage of not requiring a great deal of depth behind the instrument panel. Generally, some panel space is available outboard of the flight instruments but little depth.

Other possibilities include head-up displays and replacing one or more electromechanical indicators with advanced technology indicators which integrate the old functions with the new ones.

Several considerations must be faced with respect with respect to modernization of older commercial aircraft. These are the inherent inflexibility of electromechanical design resulting in difficulties in modification, the high cost of aircraft downtime and the very real problems of introducing awkwardly implemented instrumentation into a flight station optimized for another era.

COLLISION AVOIDANCE

The Electromechanical Aircraft are older generation aircraft having electromechanical instruments. They may or may not have equipment that would be useful for integrating ATARS and BCAS information into the cockpit. The same is true for later incorporation of CDTI. All of these system concerned with either presenting to a pilot his tactical situation relative to surrounding aircraft and/or information for escape maneuvers to avoid collisions. It must be kept in mind that these are automated systems

operating in parallel and complementary to the existing separation assurance system where air traffic controllers, through their own conflict alert system and monitoring of the air traffic situation, advise pilots of proximate aircraft and avoidance maneuvers.

The above systems call for electronic displays. If an aircraft has a modern raster scan digital color radar, the job of presenting information to the flight crew becomes easier. If not, the choices reduce to scabbing on electronic displays wherever suitable panel space is available or substituting new instruments in place of existing electromechanical instruments.

Instrument Panel Space

Spare instrument panel space on transport aircraft is scarce. Some is unusable because of control column or other blockage of view. Other space has not been used because of depth limitations. It is not apparent in observing older aircraft instrument panel designs that conservation of space was uppermost in designers' minds. Other than providing priority locations for the primary flight instruments on the left and right instrument panels, the remainder has been used for a variety of functions which are installed in random locations. Use of the glareshield for display of information has been increasing over the years. This is priority space for display and controls because of its head up location.

Even with the present clutter and scarcity of space it is felt that suitable locations can be found for specialized electronic flat panel displays in the cockpit. Compromises will have to be made in the amount or information provided but additional information beneficial to safety can be gotten into the cockpit without requiring redesigning the aircraft instrument panel at a prohibitive cost.

In addition to spare panel space, there are existing electromechanical instruments which are candidates for redesign or changes of design concept which would facilitate integrating the new information into the cockpit. The vertical speed indicator, as suggested by the FAA, can be modified using electroluminescence technology to provide "Fly Up-Fly Down" commands for conflict resolution together with climb or descent limit information when appropriate. Space now required by clocks can be made available for other applications by substituting a digital flat panel clock. It is felt that with a detailed study of individual aircraft instruments that other candidates will be found that can be modified at a tolerable cost/benefit ratio.

Information Display

This discussion includes ATARS, Active BCAS and CDTI:

ATARS - This system makes available a range of information from a basic minimum for use in austere equipped aircraft to more elaborate for use in aircraft with electronics capable of taking full advantage of it. The system provides advisories on proximate but non-threatening aircraft, threatening aircraft, and a resolution service to avoid potential collisions.

For non-threatening aircraft, the pilot needs bearing, range and altitude information so that he can be made aware of and visually acquire aircraft when in Visual Meteorological Conditions (VMC). Visual threat evaluation is difficult at the longer ranges and additional information in the cockpit is helpful if an aircraft becomes a threat. Under these circumstances information is needed on the speed, heading, and vertical speed of the other aircraft so the pilot can plan ahead on maneuvers he should avoid. If the threat projects to a conflict, then the pilot needs information that will resolve the conflict but would not lead to conflicts with other aircraft.

As a general approach to integrating ATARS into older vintage aircraft, it is suggested that flat panel technology be used with proximate and threatening advisories being presented in alpha-numerics on one display and an analog format maneuver director presented on a second display. These displays would be duplicated on the left and right side of the cockpit. The top part of the Traffic and Threat Advisory Panel would be reserved for threat information and the bottom for traffic information. The "Threat" portion would include information on bearing, range, altitude, threat heading, threat vertical velocity (plus or minus) point of closest approach, ATC control status, and ATARS equipment. ATARS altitude data is transmitted as relative altitude. This information could better be assimilated by adding in ownship's altitude in the aircraft. The proximate advisory portion of the display would have a reduced amount of information as follows: bearing, range, altitude, proximate aircraft heading, and ATC control status.

It is suggested that small LED or LCD flat panels be installed as close as possible to the ADI's to display positive and negative resolution advisories. A matrix of LED's or LCD's would be used for direction arrows for "Fly-Up", "Fly-Down", "Fly-Right", "Fly-Left", together with "X"s to indicate directions to avoid. The "Fly-Up", "Fly-Down" portion of the resolution display can also be used to present active BCAS originated commands.

CDTI can be added to older aircraft if a raster scan color radar display is aboard or space can be found to install a CDTI display. As mentioned previously, the source of CDTI data has not been established. In any case whatever the method used, provisions must be made in the system and in the cockpit for pilot selection of the range and altitude limits in which the pilot is interested. If a ground-based system is used, this selection should be transmitted over the data link to conserve channel demands on the system.

DATA LINK COMMUNICATIONS

Tactical messages, minimum safe altitude warnings, and extended length message capabilities are planned for the DABS data link function. Tactical messages, for example, include messages of clearance and altitude assignment confirmation. Safety is enhanced by having these messages displayed in the cockpit in addition to the tactical messages delivered by voice from air traffic controllers.

A simple approach would be to install a single small flat panel tactical communications display in the center instrument panel area which could be read by any crew member. The panel would be self contained with driver and

ARINC 429 data bus receiver and would connect to the DABS transponder via a 429 bus. Minimum safe altitude warnings could be accommodated by a small dedicated display mounted near the ADI on each side of the aircraft. An ARINC 429 receiver decodes the warning and triggers an aural alert. The warning remains on the indicator until the aircraft climbs to a safe altitude and the warning clearance message is received over the DABS data link.

An ideal solution to the problem of integrating data link communications into older aircraft cockpits would be a new development which combined DABS and ACARS data link control into a single panel which also contained a printer. The requirements for this panel would be: (1) Display of several lines of alpha-numeric data, (2) Alpha-numeric data entry keyboard, (3) DABS/ATARS selection, (4) Data identification and instruction function keys, (5) Microprocessor control and memory for message/menu storage, and (6) A silent printer for hard copy.

Another approach provides DABS facilities only with a modest data entry capability, primarily for initiating requests to the ground for information, and a printer as the airborne readout device for extended length messages. The primary purpose of this system is to obtain ETIS and weather information.

The compact panel contains a one-line scratch pad display, a telephone-type pushbutton alpha-numeric data entry panel and function keys. It is microprocessor controlled, formats the data into an ARINC 429 format, and upon command, transmits the data over a low speed 429 bus to the DABS transponder. Replies from the ground are routed to a printer over another 429 data bus. The pilot obtains data identification and location codes from printed material. These codes are entered through the keyboard, verified on the scratch pad, entered and transferred to the message buffer in the DABS transponder. Replies are automatically printed out on the printer.

Another alternative to an on-board printer is available if a raster scan weather radar is installed. By interfacing the DABS control panel with the radar indicator, messages can be displayed anytime the weather radar is not required.

MLS

User needs will determine when and how MLS is retrofitted into older aircraft. The simplest installation would consist of an MLS receiver, controls for frequency, elevation angle, azimuth angle, and display selection, plus one or more C-band antennas. The simplest installation is suitable for straight-in ILS type approaches using deviation signals from the MLS receiver as input to standard instruments and autopilot as is done with an ILS receiver. Marker beacons are used for distance information or DME may be used for MLS stations having co-located DMEs. In the latter case, pairing of the DME and MLS must be accommodated in the modification design and provisions made for readout of the DME.

If capability is needed for more flexible approaches, such as segmented or curved, then an MLS guidance computer will be required. It is not known at this time to what extent existing ADI's and HSI's will support more complex approach paths. This is dependent upon a great deal of further flight

testing. If standard instruments will support more sophisticated approach paths, then some demand for retrofit of guidance computers can be expected wherever there are benefits to airline operations.

The subject of defining approach paths in a guidance computer merits some discussion. It is probably not a good idea to have approach paths defined to the computer by pilot input unless the input is uncomplicated and can be done with a small amount of attention required. A better approach would either have the approach definition data linked from the ground or have the pilot select a designated path from prestored standard terminal approach routes for MLS equipped aircraft. Prestored approaches in an evolving MLS network will present a problem to users. Reprogramming of all guidance computers within an airline, for example, would be required everytime a new MLS installation came on line and standard approach paths for that particular airport were defined. Fortunately, erasable programmable read only memory (EPROM) technology is suited to this type of scenario. Airlines would need facilities for reprogramming and verifying EPROM's.

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APPENDIX A

AIRCRAFT DEVELOPMENT SCENARIOS 1985, 1990, 1995

1985 FLIGHT CONTROLS

Flight controls are discussed under the following headings:

- o Primary-Secondary Flight Controls
- o Active Control Systems
- o Autopilot/Flight Director/Autothrottles
- o Flight Control Instrumentation

Primary-Secondary Flight Controls -

Primary and secondary controls in 1985 will be as represented by the Boeing 767 and 757, the Lockheed Advanced TriStar derivative, and the McDonnell-Douglas Advanced DC-10 derivative. Conventional column and wheel controllers will still be in use, however, they will be streamlined as much as possible for good visibility. For the most part, conventional controls will also be used for the rudder, flaps, and slats, ailerons, spoilers, and trim, however, more automation will be evident in the operation of the flight control surfaces with the advent of active control systems (aileron) and automatic direct lift control (spoilers) for greater fuel efficiency in cruise flight and in the terminal area.

The pitch, roll, and yaw maneuvering controls will have blended mechanical and electrical inputs to the control surface servo systems. Primary reliance will be on mechanical systems with, electronically derived inputs that can be used instead of, or to modify, the manual inputs. Pilots will use these electronically derived inputs to operate the controls most of the time throughout all the phases of the flight.

Some alerting information and checklist procedures will be presented by CRT display; a modest synthetic voice capability will be offered for presenting this information under high visual workload conditions.

There will be a moderate level of integration of the primary/secondary control systems with AIDS and other dedicated equipment for purposes of on-board fault analysis. Automated troubleshooting procedures and verification tests will be in general use for the Flight Management System (FMS), the Active Control System and the autopilot, however, maintenance activities for most of the other aircraft systems will be performed manually by technicians using printed information and procedures.

Illuminated pushbutton switch panels on the overhead will be used to control the hydraulic and electric power to the surface servo systems. Both status (on/off) and integrity information based on the results of built-in monitoring of the surface control systems will be displayed on these illuminated pushbutton switches.

Active Control System (ACS) -

Active control systems are feedback control systems which sense aircraft motion and diminish structural responses by introducing counteracting control forces or moments. Active controls are therefore not intended to directly influence the flight path of the vehicle. Rather, the active control system can be integrated with the flight control system to achieve a multitude of system control functions. Among these are the following:

- o manual command augmentation
- o stability augmentation (pitch, roll, and yaw)
- o wing load alleviation
- o flutter mode stabilization
- o direct lift control
- o rudder load limiting control
- o automatic ground spoiler control

The use of active control is in many cases the favored trade study alternative to larger stabilizing surfaces, additional structural weight, and/or higher fuel consumption. It is predicted that for the 1985 time period the active control functions will be non-flight-critical for the normal operating envelope but may be critical for operation in the boundary areas of the service flight envelope.

The ACS is a computer-based system of electrohydraulic controllers integrated with the other FCS surface servos. Computer organization is dual-dual or triplex for fail-operations or fail-passive fault tolerance. Comprehensive fault isolation techniques identify problems down to the line replaceable unit level.

Autopilot/Flight Director/Autothrottles -

The role of the automatic flight control system is expanding to cover a broader spectrum of flight conditions with greater positioning accuracy and with a more comprehensive set of system functions than previously available. Digital technology provides the accuracy, reliability, and computing flexibility to accomplish these objectives. Fault tolerant computer organization provides the requisite safety so that more extensive use of the systems is possible in the terminal area environment. The following functions are representative:

Autopilot/Flight Director

- o Pitch/roll attitude
- o Altitude select/hold
- o Heading select/hold
- o Vertical speed

- o Control wheel steering
- o IAS hold
- o Mach hold
- o Category III approach/land/rollout
- o Takeoff
- o Go-around
- o Lateral steering
 - Area navigation
 - VOR/LOC
 - Inertial navigation
 - Omega
- o Vertical steering
 - Area navigation
 - Energy management

Thrust Control

- o IAS hold
- o Approach/land/rollout (Angle of attack hold/throttle retard)
- o Energy management
 - Climb
 - Cruise
 - Descent
 - Endurance

The system is controlled through a glareshield-mounted control panel for mode and system function selection.

Although the system design offers the capability of completely automated flight from takeoff to touchdown, it is expected that ATC procedures in use in the 1985 time period will require some manual control in terminal airspace resulting in less-than-optimum aircraft performance and higher workloads on the ground and in the air.

1985 NAVIGATION

VOR/DME facilities will continue to serve as the backbone of domestic navigation throughout the 1985 time frame; there will however be a change in emphasis on their use. Rather than flying along prescribed VOR radials, changes in ATC philosophy will permit wider use of area navigation (RNAV) techniques whereby DME/DME and VOR/DME pairs are used for position

determining only; the aircraft's RNAV computer computes the great circle (direct) course for the flight thereby offering greater flexibility and savings in aircraft operation.

The resurgence in 3D RNAV has been generated by interest in saving fuel and is evidenced by the widespread movement to install flight performance/flight management systems into newly purchased and existing airplanes. The offer of an area navigation option with these systems is being widely accepted. New aircraft, such as the Boeing 767/757 will be equipped with RNAV capabilities as a part of its flight management system. A fully-coupled flight management system is presently being delivered on the Lockheed L-1011-500 as standard equipment. The exploitation of time and fuel savings advantages offered by these system capabilities cannot be realized without their accommodation by and eventual integration within the ATC environment.

Interest in 4D navigation is increasing. Adding precise arrival time control to 3D navigation has the potential for increasing the aircraft handling capacity of enroute and terminal airspace. The present random-in-time arrival of aircraft at enroute checkpoints and terminal area metering fixes results in labor-intensive ATC environment and the use of radar vectoring and holding techniques which greatly increase aircraft operating costs and wastes fuel. 4D navigation techniques result in the time-ordered arrival of aircraft at these designated ATC checkpoints and assures that the arrival time requirement assigned by the ARTCC computerized metering program can be met without manual intervention.

Lockheed has successfully demonstrated the feasibility of these concepts on an L-1011 flight from Palmdale, California to Dallas/Ft. Worth. It is anticipated that airlines will conduct experiments with 4D navigation in this time period; for the most part only software changes are required to add 4D capabilities to the aircraft's flight management system.

Inertial navigation systems will continue in use in the 1985 time period as the primary source of navigation data for commercial airline over-water flights. Omega navigation systems are of much lower cost and are therefore becoming popular with business aviation for transoceanic navigation. Doppler and loran-C are fading technologies; Omega navigation systems can be used to bound inertial position error at a lower cost while offering a complete navigation back-up capability. The Omega system concept is considered by most to be a stop-gap technology however with the appearance of GPS on the technical horizon.

Strapdown inertial technology will make its commercial entrance on the Boeing 767/757 series aircraft. Hard mounted accelerometers and laser gyros sense aircraft motion; the system's computer performs the necessary coordinate transforms and calculates aircraft acceleration, altitude and velocities. Present day technology makes the strapdown approach attractive for several reasons. Laser gyros are solid state with no moving parts and are therefore highly reliable. With the elimination of gimbals, torque motors, slip rings, etc, the strapdown system is simpler than its mechanical counterpart. The system provides body rates and accelerations as direct outputs thus eliminating requirements for additional rate gyros and accelerometers for the flight control systems. Laser systems, because of

these inherent advantages and lower life cycle cost, will rapidly expand in use.

The evaluation and initial airline use of the microwave landing system is expected within the 1985 period. The use of MLS will begin in a modest way and increase with time, constrained only by the economics of the terminal airspace problem. Supportive technology for utilizing MLS for performing curved decelerating approaches to relieve congestion and to help with the wake vortex problem are under current development.

The first step toward implementing MLS is to provide several ground stations across the country for operational evaluation by aircraft manufacturers and the airlines. Such an initial effort is expected during this time period. MLS installations at major hubs will provide the opportunity for building expertise and data on the ramifications of operating MLS, first using conventional straight-in approaches, then simple segment, multiple segment, and curved approaches. In this manner, data can be accumulated on the fuel savings and productivity of shortened approaches as compared to the long straight-in ILS approaches. Because of the time anticipated for developing efficient operational procedures at the major airports the evolution of MLS is expected to grow slowly.

1985 COMMUNICATION

VHF voice will still be the primary means of communications between the aircraft and the outside world in 1985. The problems of continuing heavy reliance on voice in the future are widely recognized and programs are underway to change the current situation.

Voice communications present a significant crew workload factor in today's transport aircraft. All ATC-related changes to the flight path must be dealt with by the attention-distracting procedure of tuning the radios, observing protocol, and listening for the appropriate call. A typical flight begins by tuning the Automated Terminal Information Service (ATIS) to get information such as the general weather, local pressure, wind speed and direction, temperature, dewpoint, runway in use, and runway conditions where appropriate. Another frequency is selected to obtain clearance from ground control for engine start, pushback and taxi. The tower must be contacted prior to takeoff. A fourth selection is required for departure control, then additional selections for the Air Route Traffic Control Centers depending on the altitude flown and the centers used enroute. When approaching a destination, the selection of Terminal Radar Approach Control (TRACON/TOWER) is required followed by ground control again for taxi in. At congested airports, ramp control towers which handle traffic in the immediate vicinity of the terminal require an additional frequency selection.

In addition to the ATC functions, company communications require frequency selection for forwarding messages to operations offices or for contacting company-owned communications networks, ARINC, for example, provides nationwide enroute services from its three communication centers located in New York, Chicago, and San Francisco and its network of telephone lines and radio stations throughout the country.

Voice communications also present problems in congested terminal areas with the volume of party-line communications between surrounding aircraft and the ground. Communication delays in awaiting an opening will worsen in the future.

The FAA has embarked on a program to significantly improve communications by the introduction of a digital air/ground data link, the Discrete Address Beacon System (DABS). DABS is a transponder-based system which provides primary source information for ATC surveillance and is privately addressable as contrasted with the present Air Traffic Control Radar Beacon System (ATCRBS). All ATCRBS-equipped aircraft within the beamwidth of a surveillance radar reply when interrogated; DABS-equipped aircraft will reply only when addressed.

The DABS data link will also provide a private communications link between aircraft and the ATC system; messages can be uplinked or downlinked in the stream of surveillance radar interrogations and transponder replies.

DABS will be introduced in an evolutionary manner. Several elements must in place before the system can be operationally used:

- o DABS Sensor Installation (ground)
- o DABS Transponder (airborne)
- o Data Link Interface Unit (airborne)
- o Input/output Devices (airborne)

DABS Sensors are expected to be available at a few airports in 1984. Airborne DABS transponders will have provisions for the data link interface and for the Beacon Collision Avoidance System (BCAS). DABS-linked information will initially be presented on dedicated displays, but eventually will be integrated into the aircraft's information and display system. Input devices are needed for crew access to the communications link. A printer or other bulk storage medium may prove desirable for retention of information.

Initial installations will be flying in the 1985 time frame. The methods of display and data input will vary with design philosophy and customer mandates. It is expected that a number of aircraft will already have printers aboard which were installed for the ARINC Communications Addressing and Reporting System (ACARS).

Early services expected on the data link are:

- o Takeoff clearance confirmation
- o Minimum Safe Altitude Warning (MSAW)
- o Enhanced Terminal Information Service (ETIS) which is an automated ATIS system
- o Routine enroute weather information

o Enroute altitude confirmation

ACARS has been in development for several years and has recently been put into service for two-way company communications. ACARS-equipped aircraft have an active terminal on ARINC's data communications network. The airborne unit operates by tone modulating a standard VHF communication radio set which works into a ground-based digital data processor. The system provides air-to-ground and ground-to-air signaling and digital communications with provisions for automatic or manual data entry.

First uses of the system have been automation of the 000I reports which report in Greenwich Mean Time - out from the gate, off the departing station runway, on the arrival station runway, and in to the gate. Fuel reports are also being transmitted by manual data entry. The system provides an efficient communications link when compared to voice links depending upon the options adopted by individual airlines. Through interfaces with sensors, flight management system, Aircraft Integrated Data Systems (AIDS), etc., any desired data aboard an aircraft can be obtained.

ACARS is currently in its early stages of operational experience. Its scope will grow with time as users of information are made aware of its capabilities and efficiencies for communications.

1985 FLIGHT DECK INSTRUMENTATION

The 1985 flight station will contain a combination of electronic displays and conventional electromechanical instruments. The electronic displays will be somewhat more flexible than the devices they replace; but will basically implement traditional instrument functions using CRT adaptations of current electromechanical instrument formats.

An electronic flight display will replace the ADI, will incorporate features to reduce scan requirements, and will provide additional information pertinent to the particular flight segment. The conventional artificial horizon indication of attitude will be retained. Airspeed, altitude, vertical velocity, and steering information will be displayed either digitally or as analog data depending on the flight phase and need. Takeoff data may be added for this flight phase. During final approach and landing, wind data will be added and, perhaps, engine thrust requirements.

The electronic HSI will display more information than the instrument it replaces. The basic EHSI format will be a plan view of the desired ground track and selected waypoints in the vicinity of the aircraft. Conventional navigation information such as heading, course and course error can be overlaid with weather radar data when selected; other data such as distance and time to waypoint will be displayed digitally. Some aircraft will have indications of minimum safe altitudes and obstacles in terminal areas. The more sophisticated aircraft will provide predictor paths and time boxes to facilitate 4-D RNAV operations.

Electronic engine instrument displays will be available on some aircraft; their format will be similar to the electromechanical devices they have superseded. Such information as tachometers (N1,N2), engine pressure ratio (EPR), turbine inlet temperature (TIT), and fuel flow (FF) will

continue to be monitored with improved capability to set command and alarm bugs.

An electronic Caution and Warning System (CAWS) display will be used in conjunction with visual and aural master alerts and some synthetic voice capability to present advisory, caution, and warning information in an unambiguous and prioritized manner. Implementation will be different for the various aircraft types but will all be designed to standard guidelines.

A variety of controls and data input devices will find their way into aircraft by 1985. Design movement is away from dedicated system control panels toward increased functional integration. This is an evolutionary process, however; for the 1985 time period there will still be partial collections of functional activities in the movement toward overall systems' management.

Multifunction pushbutton and keyboard controls are emerging in present-day aircraft. Some displays now have switches arranged along the side of a CRT with the function identified on the display adjacent to the switch. This allows selection of pages from a menu of functions without a commensurate increase in panel space requirements. Multifunction controls of the future will utilize touch panels and legends appearing on the display area itself for control.

The need for entering data into the various digital systems has brought about a variety of data entry techniques. The entry of routine, predictable data can be facilitated by paging through a menu of possible selections until the desired entry is displayed adjacent to one of several entry selection push switches. Exceptional data, however, cannot be dealt within this manner. The entry of numerical data is best accomplished via a compact numerical keyboard, much like that of a hand calculator. Since only ten digits are involved, this method is fairly efficient. Fortunately the largest requirement for exceptional data input is numerical. Alpha data, however, presents a tougher problem because of the larger number of possible selections that exist. The method chosen for entering exceptional data into the L-1011 flight management system utilizes a keyboard similar to that of a touch telephone pad containing one number and three alpha characters on each pushbutton. The first depression of the switch enters the number; subsequent depressions enter the first, second or third alpha character. Methods like these will continue to be used in the 1985 time frame, however, much developmental activity in using voice recognition techniques for data entry will become evident.

1985 FLIGHT MANAGEMENT SYSTEMS

Perhaps one of the most important developments in aircraft systems design has been the introduction of the flight management concept. Flight management is a systems integration technology precipitated by an increasing flight deck workload. Its genesis was the development of area navigation systems which enabled flight plans to be stored in computer memory and permitted automatic tuning of the aircraft VOR/DME receivers along the flight path. These systems were later developed to provide guidance and steering in both the horizontal and vertical planes. Other options, such as moving maps, were also developed to assist the flight crew in dealing with the navigation

problem. Unfortunately, RNAV technology was ahead of its time as the ATC environment was not ready to take full advantage of its potential.

The increase in fuel costs, however, has provided justification for developing systems to manage aircraft performance. Performance data is stored in a computer and the information gathering processes and calculations for optimum thrust settings are automated. These performance management systems therefore not only provided more precise control of aircraft performance, but also served to greatly reduce crew workload requirements.

Of the several performance management systems that are available today, some are of the advisory type which display the parametric settings of speed and thrust to achieve the desired climb and cruise performance under prevailing conditions. Other systems are designed for closed-loop operation so thrust and speed will automatically track. These systems also provide information for one engine out operation so a pilot can quickly determine his performance capabilities under this condition.

The flight management system concept integrates the functions of RNAV, aircraft performance data, and propulsion control into a system which can be flown manually from displays or coupled for automatic flight and thrust control. The aircraft's progress along the flight plan can be monitored by alphanumeric and graphic electronic displays. Information stored for flight planning purposes (airport data, SIDS, and STARS) can be stored and retrieved as needed. Waypoints can be added or deleted. Optimum speed and climb rate is maintained by pitch commands to the autopilot and EPR commands to the autothrottle. In cruise, optimum speed and altitude are calculated and executed automatically. Likewise, the descent to the terminal airspace entry point is calculated and initiated at the correct instant, all under automatic control. Flight management systems, therefore integrate all appropriate related functions, provide considerable reduction of crew workload, and deliver current information to the crew for dealing with changing conditions.

1990 FLIGHT CONTROLS

The same functional complement of maneuvering and trim controls will be applicable to the 1990 aircraft. The blend of electrical and mechanical input systems, however, will weigh more heavily in favor of electrical input controls. The electrical input system will be increased to full authority accompanied by further simplifications made to the mechanical input system, possibly including the use of single cable runs. Further tailoring of the control column/wheel will permit even greater visibility of the main instrument panels. Potential exists that the rudder controls could be all electric. The enabling technologies to permit this transition from primarily mechanical to electronic controls include advances in fault tolerant system structures and fiber optics. These control functions will be integrated into the active controls computer subsystems as they, like the active control functions, are an integral part of the basic airframe. Conceivably, positioning accuracy requirements in the terminal area during normal operations may dictate lesser manual control and greater reliance on the automatic flight controls. As pilot acceptance of and facility in using control display units (CDUs) is gained during the 1980's, improvement in the human factor design such units will allow the elimination of dedicated

overhead control panels for flight controls. The system management CDU may also incorporate the functions normally performed by the Autopilot/Flight Director Control panel. The greater reliance on electronic input-systems for primary and secondary control is also partially motivated by the evolution in aircraft configuration design to the greatest extent that the fault tolerant system technology will allow for an energy efficient design.

The new generation of ATC systems and navigation aids make it feasible to expect more stringent positioning accuracies throughout the flight, thereby increasing the capacity of existing facilities and decreasing the use of manual controls in the terminal area.

The functional complement of the autothrottle, autopilot, and flight director system will not be drastically altered from the 1985 airplane, but the integration of these functions with the navigation and guidance function and the pre-programmability of the various operating mode selections will be departures from today's standards. The overall system is expected to automatically control the flight path of the aircraft from takeoff to landing. This will drastically change the pilot's role in the flight station. Overall workload should be reduced, aided by a new generation of ATC systems. The pilot will be more attentive to his role as system manager and will use his manual input systems for maneuvering control to a lesser extent, probably only during extraordinary operating conditions.

Several unique system operation options can then be offered the pilot.

- Full flight profile AFCS preprogrammability
- Partial flight profile AFCS preprogrammability
- Manual preprogrammability.

Preprogrammability refers to the ability of the autopilot control logic to automatically reconfigure the mode selection to cause the aircraft to follow a preprogrammed flight path. Manual selection of modes inflight will still be possible; the pilot may choose to make the mode selections if he so desires.

For full flight profile preprogrammability, the control logic would be set-up to control the autopilot mode selection sequence from takeoff roll to engine shutdown for the particular route structure segments of the airline. The pilot would select the appropriate route segment via his system management CDU during preflight; this action would be sufficient to arm the system logic.

For partial flight profile preprogrammability, the control logic would be set-up to accept the fixed segments of flight (e.g., cruise transition to descent/approach/landing). The pilot would then specify the flight segments and input the route segment being flown.

For manual preprogrammability, the control logic would accept pilot inputs to establish an autopilot mode selection sequence for a flight segment not on an established route. The pilot would make these selections prior to flight.

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ANALYTICAL STUDY OF COCKPIT INFORMATION REQUIREMENTS.(U)

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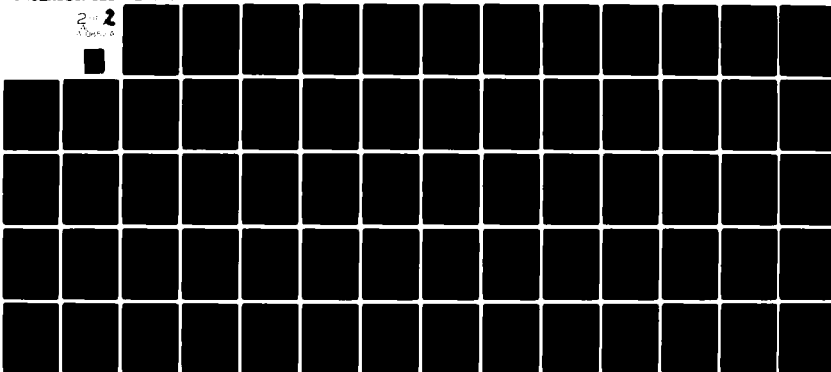
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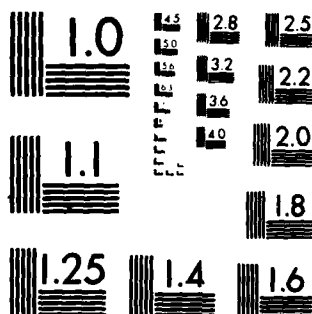
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1990 NAVIGATION

The necessity of reducing fuel costs and the recognition of advantages resulting from coordinated use of airspace and airport facilities will place increasing emphasis on the precise, flexible, integrated approach for the enroute and terminal navigation problems. Four dimensional area navigation will be necessary to adhere to schedule and separation requirements and to handle profile descents. Worldwide navigation capabilities will be improved by the introduction of the Global Positioning System which will become increasingly attractive as electronics technology allows the cost of GPS receiver/processor systems to become competitive with other navigation techniques. VOR/DME and DME/DME will continue to be the dominate navigation method for continental U.S. operation through this period, however. Microwave Landing Systems (MLS) will be introduced at airports where ILS is impractical and will gradually spread to other facilities as more aircraft become equipped and as variable approach paths become acceptable as a means of noise reduction, wake vortex avoidance and fuel conservation. Such uses will generally require much more sophisticated terminal traffic control systems to solve the metering and spacing problems.

The technology for 4-D RNAV is available now, however the system probably will not become attractive until the late 80's. Although 3-D RNAV is currently of some advantage in route planning, maneuvering and descent, the addition of schedule constraints is of little benefit because arrival in the terminal area does not guarantee an immediate landing slot. Due to uneven distribution of arrivals and the complexities of terminal area metering and control, a much more comprehensive system is required to achieve the potential of 4-D RNAV. By 1990 it is possible that Air Traffic Control will have sufficient computing capacity, the capabilities offered by the National Weather Service will be adequate and data link communications may be operational to the extent that gate-to-gate schedules could be established and consistently adhered to with 4-D RNAV would be indispensable. Indications are that 4-D RNAV will work very well in a one plane environment or in a carefully planned system but it loses most of its advantages in a randomly operating system because external influences prevent schedule adherence, which is its main function.

The Global Positioning System (GPS) will become increasingly attractive in this timeframe. The VOR/DME system has provided an adequate navigation capability within the U.S. but is not available in all parts of the world. Because of the multitude of stations required, the cost of supporting the system is high. Its chief advantage is the extremely economical user equipment required. The general advance of electronics and specifically efforts to develop special purpose integrated receivers will eventually eliminate this advantage, even with general aviation users. Commercial carriers will obtain the additional advantage of commonality of equipment between international and continental operations. GPS will reduce flight crew workload since, once turned on, it will automatically track the appropriate satellites, calculate position and provide the information to the navigation system. Manual selection of VOR/DME channels is eliminated and perhaps more important, the need to determine alternate stations and frequencies if course diversions become necessary.

The Microwave Landing System (MLS) should be in relatively wide usage by 1990. During the transition period many runways will be equipped for both ILS and MLS usage and aircraft will be able to use either system. The first runways likely to be equipped with MLS will be those where ILS is not installed or is restricted because of terrain interference with the signals. Since the initial users will require ILS at other airports, their aircraft will be equipped with both ILS and MLS system. MLS offers the advantage of greater approach flexibility and should therefore be generally adopted as more airports become equipped and terminal air traffic control provides approach incentives to MLS equipped aircraft. MLS will first be used for straight in or very simple segmented approaches; as familiarity, user equipment and air traffic control computational capability develop, more complex approach patterns suited to particular aircraft and situations will be developed.

1990 COMMUNICATIONS

The implementation of several data link communications systems around the mid-1980 period will result in significant changes in cockpit design and operation by 1990. In addition, the use of synthesized voice techniques will provide a means of dealing with aircraft which are not equipped for data link operation or alpha-numeric data display.

The ARINC Communications Addressing and Reporting System (ACARS) is expected to expand and provide both automatic data transfer of aircraft accounting information as well as manual alpha-numeric communications for airlines. Manual operation will require some form of data terminal (a keyboard and either a printer or an electronic display). ACARS usage is primarily a company function and its application will be largely determined by economics.

The Discrete Address Beacon System (DABS) will provide a data link for Air Traffic Control functions. Although its use will probably be optional, the advantages it offers are significant and its widespread usage would reduce the need for voice communication. In particular, it will provide an unambiguous means of transmitting clearances, weather data and collision avoidance information both automatically and on request. Two-way manual operation will require an alpha-numeric keyboard and a printer or display.

In contrast to ACARS, much of the DABS data is of an essential nature. If an airline elects to not use the system (or to have only a minimal system), the information must still be made available. Since more and more of the ATC operation is being automated, the ability of the ATC computer system to communicate directly with the pilot is desirable. A potential solution to this problem utilizes computer selected, standardized ATC messages combined with the aircraft ID number and voice generation technologies. Pilot acknowledgement could make use of the aircraft identification feature.

Several flight functions may eventually be handled by data link communications with minor, if any, involvement of air traffic controllers and aircraft pilots. These include automatic radio channel selection by DABS data link, transfer of DME navigation parameters by DME up-link and the

designation of MLS approach paths by the MLS up-link.

1990 COCKPIT INSTRUMENTATION

The 1990 flight station will profit from several years of experience with systems integration and electronic displays. Current work in human factors research will provide guidelines for designing cockpits for greater efficiency, and improved interaction between the pilot and aircraft. Instrument formats will be optimized to reduce reaction times, primarily by clustering information required for each particular flight function.

The electronic flight display will probably represent the most radical departure from current designs. The flexibility of CRT presentation, the increasing power of micro-computers and developments in 3-D graphic techniques will permit realistic presentations of the optimum flight path and predicted deviations in course and speed. Control cues will be integrated into the symbology to suggest the proper pilot reaction during manual flight or when a takeover from auto-flight becomes necessary. Data required for immediate decisions by the pilot will be presented through this display primarily in analog form.

The electronic navigation display on the other hand will likely be an evolutionary development of the 1985 ground track display. Better definition of information requirements, improved symbology and better information availability from sensors, data link and stored on-board sources will result in an instrument which will provide a comprehensive indication of position and surroundings for short-term planning and navigation.

Much of the aircraft systems information currently presented for pilot/copilot monitoring will be pre-processed so that only essential data and deviations from normal operation are displayed. Engine settings will normally be made by auto throttle as determined by the auto-flight system, based on pre-programmed considerations of fuel economy or 4-D navigation requirements. As a result, engine instruments will mainly be used for problem confirmation and analysis and for manual back-up. Similar considerations apply to fuel flow, surface position, trim, hydraulic pressure and gear position indications. Several multi-function displays would make possible the monitoring of these functions when desired, without the necessity of dedicating large portions of panel space to seldom used instrumentation. In addition, the multi-function displays could be used to provide back-up for the primary flight displays, to display stored checklists, maps, flight plans and to display data link information.

Some information output will be accomplished by synthetic voice. This is presently being done by the Ground Proximity Warning System (GPWS) and will likely be widely used in cockpit alerting and warning systems and possibly for altimeter output during instrument approaches.

Substantial progress should be made by 1990 in reducing requirements for manual entry of data such as navigation waypoints and radio channels. Possible alternatives include magnetic card readers for flight plan input, ground selection of radio channels by data link, onboard computer storage of frequently used information such as nav aids or standard flight plans, data retrieval and function selection by voice command. Other data input

requirements will remain, however, such as DABS data link and ACARS entries. Cockpit integration and data bussing will allow each crew member to communicate with all appropriate systems by means of a single keyboard. It seems reasonable that this keyset might have an integral LCD scratch pad and be cable connected to the aircraft systems, much like a microphone. Such an arrangement would facilitate operation, reduce console clutter and eliminate the right hand-left hand input requirements imposed by pilot and copilot seating arrangements.

1990 COLLISION AVOIDANCE

The primary method of aircraft separation will continue to be the ground base Air Traffic Control Service which will utilize increasingly more sophisticated computer facilities to project and avoid conflict situations. This service will be backed up by the ground based Automatic Traffic Advisory and Resolution Service (ATARS). The aircraft based Beacon Collision Avoidance System (BCAS) will provide backup protection to aircraft outside areas covered by ATARS but under ATC surveillance, and primary protection to aircraft in remote areas. All of these systems are dependent on both conflicting aircraft being equipped with transponders and at least one aircraft being equipped to process and display conflict avoidance commands.

1990 PROPULSION SYSTEM CONTROL AND MONITORING

Larger (60,000 lb. thrust) engines running at higher temperatures (2700 F. TIT) with closer tolerances and increasing use of light metals will require more extensive monitoring of vibration, temperatures and pressures to maintain efficiency and assure engine life expectancy. Ambient conditions and engine parameters in addition to 4-D navigation and aerodynamic characteristics will determine auto-throttle commands. Vibration amplitude and phase angle will be monitored and stored to permit on-ship fan rebalancing for reduced engine wear. Transducers embedded in bearing hubs will allow some incipient failure detection before catastrophic damage occurs. Engine temperatures will become more critical, requiring monitoring and control of engine case heating and cooling.

Generally, the crew will be buffered from these changes by the increasingly more sophisticated control systems. Parameter evaluation and control computation will be done by the flight management system so that the crew normally would only input objectives such as waypoints and schedule or minimum fuel requirements.

1995 FLIGHT CONTROLS

Some fairly dramatic advances in technology will occur to allow significant streamlining of the flight station and increased margin of safety by reducing pilot workloads. The following innovations are expected to be put in service in this time frame:

- o Completely electronic input control system using fiber optic signalling techniques.
- o New input controller mechanisms... Electric Stick Grips for pitch, roll, and yaw inputs...

yaw control removed from pedals which are used for braking only.

- o Wing torsion load relief controls employed, involving wing tip control surfaces.
- o Trim control devices introduced to maintain optimum wing load conditions for off-design cruise flight conditions.
- o Transition from irreversible hydraulic powered control surface servos to all-electric surface servos, eliminating the need for hydraulic power.

The innovations applied to the automatic flight control systems of the 1990's will be consolidated into state-of-the-art digital system structures for the turn-of-the-century aircraft. Functionally, the system will perform the same tasks in an equipment complement which will be more compact, requires less power, and is more closely integrated with the Navigation/Guidance, CAWS, and Warning, and AIDS Avionics. Although somewhat speculative at this time, the following developments are seen as potentially impacting the information flow requirements in the year 2000 flight station:

- o Widespread use of MLS
- o Introduction of GPS as a viable world-wide Nav Aid
- o Introduction of Cockpit Display of Traffic Information (CDTI)
- o The potential for using the DABS data link for automatic collision avoidance maneuvering.

1995 NAVIGATION

The Global Positioning System (GPS) will become the dominant mode of navigation, thereby providing unified means of worldwide navigation. Four dimensional area navigation will complement GPS by providing the computational power to go from one waypoint to the next, arriving on position, at the desired altitude, time and speed. The Microwave Landing System will provide precise approach guidance, allowing efficient standardized terminal control of aircraft arriving from all directions. High speed turn offs, possibly automated through the use of buried cables for guidance, may be used to rapidly clear runways to allow minimum separation landings. Rising fuel costs, increasing air traffic and only minimal expansion of airport facilities are expected for the next two decades. To achieve the anticipated goals of reduced fuel consumption and more efficient airport utilization, tight coordination between airlines, air traffic control centers and terminal control facilities will be required. Strict schedule adherence will, in turn, require precise navigation both in space and time.

The pressures for providing optimum allocation of resources, coupled with the ability of presently developing technologies to achieve this goal,

indicate that more and more integration will take place in aircraft and in the total system composed of aircraft, airlines and air traffic control. Navigation will play a significant role in the successful integration of these components. The future navigation system must not only provide highly accurate current position fixes, but also projections of future positions and arrival times based on current parameters. This would facilitate the selection of course deviations to maintain schedule and still minimize fuel consumption where possible.

Data link communication will provide a necessary source of frequently updated, accurate weather information which can be made directly available to the navigation computer for alternate route planning. Similarly, ATC vectoring and clearance information could be uplinked to the aircraft, displayed to the crew, and directly input to the nav computer. This would avoid typing in new vectors or waypoints and decrease the response time to ATC requests. Down linking of requested flight plan deviations could allow path projections to be compared and conflicts predicted automatically before clearance is issued. Uplinking of local terrain data, approach paths, wind data and navigation channel selection could greatly reduce the crew workload during the terminal navigation phase of a flight.

Much of the aircraft systems information currently presented for pilot/copilot monitoring will be pre-processed so that only essential data and deviations from normal operation are displayed. Engine settings will normally be made by auto throttle as determined by the auto-flight system, based on pre-programmed considerations of fuel economy or 4-D navigation requirements. As a result, engine instruments will mainly be used for problem confirmation and analysis and for manual back-up. Similar considerations apply to fuel flow, surface position, trim, hydraulic pressure and gear position indications. Several multi-function displays would make possible the monitoring of these functions when desired, without the necessity of dedicating large portions of panel space to seldom used instrumentation. In addition, the multi-function displays could be used to provide back-up for the primary flight displays, to display stored checklists, maps, flight plans and to display data link information.

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Substantial progress should be made by 1990 in reducing requirements for manual entry of data such as navigation waypoints and radio channels. Possible alternatives include magnetic card readers for flight plan input, ground selection of radio channels by data link, onboard computer storage of frequently used information such as nav aids or standard flight plans, data input requirements will remain, however, such as DABS data link and ACARS entries. Cockpit integration and data bussing will allow each crew member to communicate with all appropriate systems by means of a single keyboard. It seems reasonable that this keyset might have an integral LCD scratch pad and be cable connected to the aircraft systems, much like a microphone. Such an arrangement would facilitate operation, reduce console clutter and eliminate the right hand-left hand input requirements imposed by pilot and copilot seating arrangements.

1995 COMMUNICATIONS

Data link systems will be the primary means of routine flight communications for commercial aircraft by 1995. A great deal of this communication will be entirely automated and may encompass such diverse information as weather conditions, local obstacles, surrounding air traffic, terminal area conditions, navigation and communication radio channel selection, navigation aid location, landing approach paths, airlines accounting information, flight progress reports, enroute and terminal metering commands, altitude clearances and flight vectors.

Dependence on data link communications will affect flight station design significantly because of the need to provide a considerable amount of scratchpad and output display area. More convenient provisions will be required for data input. Console or instrument panel mounted keyboards are not an optimum means of data input. Positionable keyboards, menu selection of standard messages and speech recognition are possible options.

The human factors aspects of dealing with written information in an aircraft, as opposed to verbal communication, deserve further study. The advantages of printed flight clearances, terminal information and weather data are obvious. Less clear are the effects of eliminating the "party line" voice communication system currently in use. Crew monitoring of ATC communications with other aircraft provide information on surrounding air traffic and flight conditions. However, these communications can represent a distraction and dilute the impact of transmissions directed to the individual aircraft.

Aural information transfer has a distinct advantage during high workload periods as it does not interfere with visual activities. Similarly, spoken information leaves the hands free for other tasks. In addition, it is generally more natural to talk while monitoring another operation than to read and type. Conversely, written information may be formatted into standard pages with assigned locations for particular information (a two-dimensional structure); this would allow very rapid access for the user familiar with it. Aural information, however, is in serial format, forcing the user to wait for the desired data. A terse weather report listing wind speed and direction, visibility, temperature, humidity, barometric pressure, ceiling, storm cell location, size and intensities, etc., is an example. If put into a standard written format, the user can determine a particular parameter at a glance. He may, however, have to listen to almost the entire spoken string if he only wants ceiling.

Advances in speech and signal processing technology may allow the advantages of both methods by 1995. Synthesized speech from written text has already developed to the point that reading machines which convert an ordinary book or newsprint to spoken words are presently available for the blind. The display of a data link message on a video screen will probably be announced by a tone to attract the crew's attention. If visual workload is high at the time, the pilot could press a button on his control stick to cause the message to be voiced. If a data link reply is required, he might activate a speech recognizer, speak a few words, and hear the message spoken by a synthesizer as it appeared on the scratchpad display. If the message is correct, he would key the transmitter. The technology for practical

implementation of such a system is rapidly developing and should be well in hand before 1995.

1995 FLIGHT DECK INSTRUMENTATION

The 1995 flight station will reflect a matured displays technology coupled with a more sophisticated integration of flight systems resulting from the acceptance of data bussing and significant advances in electronics and software capabilities. Free access to information by the various aspects of the integrated flight system will considerably improve operation. In addition, a large increase in computer capability is anticipated as a result of perhaps a ten to one increase in processor speed and a hundred to one increase in memory capacity. The greatly increased computer capability, both in the aircraft and in Air Traffic Control will result in making gate to gate auto-flight standard where ground facilities are available. Enroute 4-D metering should make arrival times highly predictable, allowing pre-planning to virtually eliminate traffic holds and potential conflicts. Such planning should reduce the need for immediate decisions either in the aircraft or by Air Traffic Control.

The result will be that major flight decisions will be made by aircraft and/or ground computers monitored by flight crews and ATC personnel. Basic flight activities will be pre-programmed and will function automatically within the limits of prediction. Aircraft and ATC computers will communicate through data links to maintain schedules, resolve traffic congestion and coordinate landing approach insertion. Discrepant situations will be detected, monitors alerted and alternatives suggested based on dynamic programming solutions. If needed, critical aircraft parameters could be automatically data linked to ATC to assist in decision making.

The result of these trends will be a change in philosophy in flight station design objectives. The function of the crew will have changed from control to one of monitoring and situation management. Assuming the acceptance of 4-D nav/flight management systems in aircraft using active control technology, the pilot will be a rather sluggish link in an otherwise almost all electronic control loop. Only in extreme circumstances will the pilot likely take manual control and fly the aircraft. For such cases, flight instruments will remain.

Developmental emphasis will therefore shift to displaying other needed information: flight progress monitoring, situation analysis and consideration of alternatives. Examples might be Cockpit Display of Traffic Information (CDTI). The display of weather conditions and stored navigation maps. For such applications, large, high resolution displays and large amounts of computer memory will be necessary. Indications are that such implementations will not be unreasonable by 1995.

The possibility of alternate fuel usage by 1995 could affect cockpit instrumentation to some degree. This is particularly true if hydrogen were used due to the requirement for a large spherical storage container. Monitoring and control of the cryogenic fuel system would probably be automated and require only the capability to call up parameters when desired. The size of the storage tank, however, may effectively sever the direct access between the cockpit and the passenger section. This could make

some form of closed circuit television communication desirable. A low light level television (LLLTV) system could also be very attractive for ground maneuvering, condition assessment and as an instrument landing aid to facilitate the transition from head down to head up operation in the last seconds of a low visibility landing.

1995 COLLISION AVOIDANCE

Potentially, aircraft separation can be achieved by planning, coordination and schedule adherence. This degree of prediction and cooperation is out of the question today, but projections of electronics technology and data processing capability imply the possibility of such operation if the human element can be managed. Rising fuel costs and airport saturation are providing motivation for improved efficiency. This will be achieved with Fuel Management Systems and 4-D navigation. A fall out of these will be better schedule adherence. More accurate weather information resulting from satellite observation and better communications are currently improving flight planning and adherence. The automatic airborne weather sensing systems will provide still more specific information.

Air Traffic Control computation capability will be greatly expanded in the late 80's. A major effort is underway to develop concepts of enroute and terminal area metering which will depend on this computer capacity. To a large extent this will accomplish the separation function on a minute by minute or better basis and provide projections of conflicts in time to permit graceful resolution. As a backup to this ATC function, both ATARS and Full BCAS will be well developed by this time period.

1995 PROPULSION

Fuel availability will be the determining factor in the 1995 propulsion technology. If current trends continue with only moderate shortages and price increases, aircraft technology will not be radically affected. Improved turbofan and propfan designs, with an assist perhaps from synthetic fuels, will be adequate to meet 1995 requirements. Only severe fuel problems coupled with unforeseen difficulties in synthetic fuel production would justify the enormous expense and difficulties involved in converting the air transport system to a hydrogen basis in this time period.

Disregarding the fuel question, it is likely that engines will be more critically designed, with built in control and monitoring capability made possible by developments of dense, high temperature tolerant electronic devices. Electronic throttles using either wires or optical fiber for interconnection will be standard. Engine instrumentation will be greatly simplified with normal control and monitoring automated. The management by exception philosophy used for other systems will be extended to propulsion, in that routine information will generally be suppressed unless specifically requested.

Engine thrust will probably become the primary displayed engine parameter, and will appear on the electronic flight instrument. Manual controls for the electronic throttles, thrust reversers, etc. will be located with pilot convenience as the determining factor. Throttle settings will normally be controlled by the flight management system.

A great deal of information on engine operation such as temperature margins, vibration and efficiency will be acquired by sensors built into the engine and analyzed by engine mounted test and monitoring equipment.

DABS IMPLEMENTATION SCENARIO

The DABS Data Link is a central requirement for increasing the efficiency of air traffic operations during the next two decades. Present plans call for the first installation to be commissioned in late 1983 and the 120th site to become operational in 1988. It is anticipated that the initial data link applications will include Automatic Traffic Advisory and Resolution Service (ATARS), some traffic control information such as takeoff and altitude clearances and possibly terminal area weather data.

Although the DABS-ATARS receivers and displays may be legislated into airlines at a relatively early date (January 1985 has been proposed), the full advantages of the data link will only be realized if data input devices and display and, in some cases, a printer are available. Justification for these installations will depend on the range of services available. The utilization of some services, for instance ground selection of radio channels and cockpit display of traffic information, are dependent on the degree of flight station integration and systems sophistication.

Foresight and the flexibility of future electronic systems may allow common usage to reduce the cost of acquiring DABS data link functions. An example is the use of the full alpha-numeric keyboard and scratchpad display of a flight management system for data link I/O. The same printer used for ACARS might also be used by DABS for hard copy messages. The Electronic Flight Information Display could also display ATARS annunciations and the Electronic Navigation Information Display could provide surrounding traffic integrated into the flight path indication.

This approach should result in wide acceptance of DABS data link services by new aircraft users. The incentive to retrofit old aircraft to make extensive use of DABS facilities is not as great. It appears likely that most airlines will be content with a system that provides ATARS advisories and perhaps handles data link messages through an ACARS printer or through an updated weather radar display and added keyboard.

In most areas it will be necessary to retain the capability to support aircraft which are not fully equipped to interface with the Automated Air Traffic Metering and Control System. In order that the automated system be aware of the existence and position of aircraft in the area, a Mode C transponder on the aircraft will be essential. The system should be capable of differentiating between aircraft of various equipment configurations by means of the DABS data link (or lack of it) or through a pre-stored data base associated with the aircraft I.D. number.

Aircraft not equipped for DABS operation could still be interfaced to the automated system by converting the DABS message to synthesized voice on the ground and then transmitting it over a VHF channel. The message would be prefaced by the aircraft's transponder I.D. number. The aircraft pilot could acknowledge the message by pressing the transponder I.D. button. If acknowledgement were not received shortly, an air traffic controller would be

alerted for manual action.

The VHF channel could be reserved to use only to messages to non-DABS equipped aircraft or all DABS messages could be converted and transmitted. The former would reduce channel clutter while the latter would maintain the "party line" effect of providing insight into what neighboring aircraft are doing. In either case this channel could be monitored also by DABS equipped aircraft if additional area information were desired.

MLS IMPLEMENTATION SCENARIO

MLS offers advantages to terminal air traffic control particularly with regards to metering, noise abatement and obstacle avoidance. In addition, it offers a solution to installation problems at airports where terrain features make ILS unusable. MLS ground installations may be less expensive than ILS for small airports, extending all weather service to areas where it presently is not available.

The latter two reasons offer the greatest incentive to the installation of MLS systems in civil aircraft since reliable service is a major determining factor in commuter airline success. Development of combination ILS/MLS receivers will benefit such users during the interim period where many airports will be equipped for ILS service only.

As the number of MLS users increases, it will become advantageous for major airports to provide MLS as well as ILS, primarily for air traffic control convenience. MLS can provide a short final approach for the smaller and slower commuter aircraft, which should reduce problems resulting from wake vortex and speed differences when incompatible aircraft are mixed in long final approaches.

Adoption of more sophisticated area navigation systems by the major airlines and the acquisition of more powerful computing facilities by air traffic control will make MLS even more valuable in the terminal area. MLS will allow alternate approach paths to become a practical means of providing separation and metering in dense traffic situations. This application of MLS will probably be relatively slow in developing, however, unless considerable incentive is provided to encourage airlines to install MLS on aircraft operating in routine airport environments.

An example of advantages which could be offered MLS equipped aircraft would be the IFR use of alternate runways such as Washington National 18, Kennedy 13L or Newark 11. By providing a highly accurate terminal navigation reference which is virtually unaffected by terrain features, MLS will allow the use of runways presently restricted to VFR or RNAV approaches because of obstacles or noise abatement requirements which preclude ILS approaches.

MLS OPERATION

An aircraft would navigate into the MLS coverage area using conventional 3-D navigation methods. The crew would select the appropriate MLS approach and activate the system. Waypoint coordinates would be obtained from the MLS data frame and would be compared to MLS derived present position data in terms of distance, azimuth and elevation to the runway to generate this

distance, bearing and glideslope to the outer waypoint is easily calculated by converting the aircraft and waypoint coordinates to the runway coordinate reference system, subtracting and converting the results back again. This information could then be compared to the current course and glidepath to derive psuedo glideslope and localizer deviations to the outer waypoint. In the vicinity of the outer waypoint, the next waypoint would be selected. This procedure would be repeated automatically until the runway was reached.

4-D AREA NAVIGATION IMPLEMENTATION

Four dimensional area navigation, when combined with fuel management and a sufficiently sophisticated Air Traffic Control System, offers considerable advantage in safety, scheduling, airport utilization and fuel savings if the necessary airline cooperation can be achieved. Without ATC advances and coordinated airline arrival scheduling, 4-D RNAV and fuel management savings can rapidly be burned off in holding patterns in the terminal area. In fact, the effect of "de-randomizing" arrivals during peak air traffic periods could make the present situation even worse. If the price of fuel continues to rise, however, and the present stochastic arrival situation were to become deterministic through 4-D RNAV and effective metering, it is very likely that the airlines would accept preassigned landing slots during terminal saturation periods.

The problems involved in such a system are considerable, but the solution will be well within the scope of 1990 technology. Several major tasks must be accomplished, some of which are already well underway. The most complex however, will be that of evolving a system embodying new philosophies and technologies concurrently with the operation of the existing system.

The ultimate system would have aircraft take off and achieve waypoints on a predefined schedule which would result in overall minimum cost (fuel, crew and maintenance) while maintaining appropriate enroute separation from other aircraft. Some deviations must be expected to account for unanticipated weather and traffic situations, but these should be held to a minimum by improved forecasting and traffic control. Each aircraft would begin descent at the appropriate point and rate to pass through a metering fix at a preassigned altitude, airspeed and time, and then be meshed with other traffic in such a way as to arrive at touchdown with the appropriate separation in spite of the different flight characteristics of the aircraft involved.

The technology for providing on-schedule arrival at the end of descent point is available in 4-D RNAV system currently under development. Tests have shown that the equipment works very well in a one aircraft environment. Problems arise however, when other air traffic must be considered.

These problems fall mainly in the area of air traffic control. From the beginning of descent point, a wide variety of aircraft flight paths must be coordinated. Aircraft of different flight characteristics, coming from different directions and at different altitudes must be sequenced to land with minimum separation dictated by airport capacity, weather and vortex considerations. Consideration must be given to incompatibilities of different aircraft resulting from type, weight and equipment capability.

Because of the wide variation of aircraft speeds during descent in the terminal area, provisions must be allowed for providing proper separation until the aircraft are put in trail for final approach. At that time spacing must be appropriate so that sufficient separation is maintained until touchdown in spite of speed differences. The controller is faced with a sequence of problems, each multidimensional, constantly changing and depending on the others. Velocities and trajectories of each aircraft must be observed and future positions predicted and controlled to maintain separation until touchdown. To this should be added the constraint of minimum fuel consumption within limitations imposed by passenger acceptance of maneuvers. This task exceeds the capabilities of the unassisted air traffic controller. Computer programs are currently being used to aid the controller and are increasing in sophistication to handle the more difficult problems as they are recognized.

Communications will play an increasing role in the overall efficiency of the civil air transport system. Optimum preflight planning will depend on a better knowledge of weather cells, turbulence and winds aloft provided by weather services, and by enroute feedback from pilots and onboard automatic monitoring equipment. Minimum diversions enroute will depend on similar information relayed to the aircraft. Longer range conflict prediction will allow separation with minimum effect on schedule and fuel. In order to estimate descent trajectories and terminal area maneuver options Air Traffic Control will need information on aircraft flight characteristics. Some of this information might be pre-programmed but such dynamic information as total weight (a function of passenger count and fuel remaining) would best be acquired by data link when the aircraft arrives in the control area. The ability to uplink radio channel data, vectoring and clearances for cockpit display or direct entry could greatly reduce ambiguity, response time and workload for both the pilot and the controller.

To achieve the goals of more effective airport utilization and reduced fuel consumption, an integrated effort of aircraft and avionics manufacturers, aircraft operators, and Air Traffic Control will be necessary. Schedules must be realistic and must consider airport capacities on both ends of the trip. Flight management equipment must be available to define and maintain waypoint schedules, climb and descent profiles, diversions and compensation maneuvers based on cost or fuel minimization and schedule constraints. Air Traffic Control will have to develop the capability to provide enroute and terminal metering services which will provide incentive for airlines to obtain and use sophisticated flight management systems and to coordinate schedules so that airport saturation is avoided.

APPENDIX B

INFORMATION BREAKDOWN STRUCTURE

COCKPIT INFORMATION REQUIREMENTS

This appendix contains 248 cockpit tasks which have been identified in the study. The information required to do these tasks is defined under the heading "CONTENT". Where the information comes from and who or where it goes to are listed under the headings "SOURCE" and "DESTINATION" respectively. The information is classified as follows:

- Class 1 - Safety/Aircraft Control
- Class 2 - Monitoring/Systems Management
- Class 3 - Trip Functions
- Class 4 - Planning
- Class 5 - Administrative

The "ATC SENS." column is answered yes or no and refers to whether or not a cockpit task is sensitive to the ATC system.

The function being performed is listed in the last column. Sixteen functions are identified and their definitions are attached. These functions group information into categories that belong together.

The tasks are grouped by operational phases from preflight through flight and ending with taxi in and shutdown. Some of the functions are omnipresent and these are listed at the beginning under the heading of "UBIQUITIOUS". Notes, listed below, are used throughout the tasks to flag areas where tasks are changed by the implementation of later technology.

FUNCTION DEFINITIONS

- o Collision Avoidance - The process of avoiding aircraft conflicts based on ground or air derived information.
- o Aircraft Guidance/Control - The process of controlling the course of an aircraft by means of error information developed from guidance sources.
- o Navigation - The process of determining position, direction, distance, and time.
- o Communications - The process of transferring information from one source to another.
- o Propulsion - The process of controlling an aircraft's propulsive force.

- o Systems Control - The process of controlling an aircraft's systems operating modes.
- o Systems Status - Monitoring the operational status of aircraft systems.
- o Alerting - The process of getting the attention of a flight crew to a situation which may require their action.
- o Advisory - The process of informing with no implication of action required.
- o Planning - The process of gathering and manipulating data to be used at a later time.
- o External Environment - The process of gathering information on external conditions/situations.
- o Consumables Accounting - The process of consumable accounting aboard the aircraft.
- o Configuration Control - The process of configuring an aircraft for a particular flight mode.
- o Verification - The process of gathering information which increases confidence.
- o Emergency Control - The process of controlling emergencies.
- o Administrative - The process of keeping and updating records.

NOTES

1. Manual flying performance is enhanced when steering is provided by a flight director.
2. Tasks may be accomplished automatically, at pilot option, with autopilot and automatic thrust controls.
3. Function is automatic when aircraft is RNAV equipped.
4. Automatic when autopilot is used.
5. For INS equipped aircraft, alignment is started at this point. For GPS equipped aircraft, satellite acquisition is started.
6. Not required when aircraft equipped with DABS and Enhanced Terminal Information Service (ETIS) is available.
7. Data Link when DABS service is available.
8. ACARS equipped aircraft may report automatically.

9. Canned D/L msg when DABS service is available.
10. Received by voice on non-DABS aircraft, by data link (ATARS) on equipped aircraft when service is available.
11. DABS aircraft with RNAV receive a series of waypoints for pilot entry into his navigation computer when service is available.
12. Aircraft may be flown with a 2-pilot crew in 1990-1995.
13. RNAV equipped aircraft or aircraft equipped with MLS course computers using airports having MLS with DME.
14. Aircraft equipped for straight-in MLS approaches would nominally be set for "0" deg. az. and "3" deg. elev. and no further action by the crew would be required.
15. Flight management system will perform this function when aircraft is equipped and system is engaged.

PHASE: UBIQUITOUS

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Control attitude (Manual) Note 1, 2	Pitch angle/roll angle	Vertical reference display	P1, P2 - pitch, roll controls	1	No		Aircraft guidance/control
2. Control airspeed/mach (Manual) Note 1, 2	CAS/mach, pitch, thrust	Airspeed, pitch and thrust displays	P1, P2 - pitch/throttle controls	1	Yes		Aircraft guidance/control
3. Control altitude (Manual) Note 1, 2	Barometric altitude, vertical velocity, FPA	Altitude, pitch and vertical velocity display	P1, P2 - pitch/throttle controls	1	Yes		Aircraft guidance/control
4. Control heading (Manual) Note 1, 2	Heading referenced to magnetic/true north	Heading displays	P1, P2 - aileron, rudder, controls	1	Yes		Aircraft guidance/controls
5. Control vertical trajectory	Flight path angle (FPA), potential flight path	Display	P1, P2 - pitch/throttle controls	1	Yes		Aircraft guidance/controls
6. Provide navigation intelligence	Navigation plan	Flight plan aeronautical charts, flips, ATC controllers, weather, fuel FFE., NOTAMS	P2, P1 - Nav. radio tuning or nav. computer data entry	3	Yes		Planning
7. Horizontal navigation, Note 3	Position, waypoint in use; course, distance and time to waypoint in use; course deviation; nav radio in use and channel; nav radio preset and channel, weather presentation	Automatic or manual computation, nav. system and displays	P2, P1	3	Yes		Navigation
8. Vertical navigation, Note 3	Waypoint coordinates of climb/descent start and end points	Manual computations or vernav cptr/display	P2, P1	3	Yes		Navigation
9. Horizontal guidance, Note 4	Steering, deviation, heading	Nav. system, magnetic compass, ATC	P1, P2, autopilot	3	Yes		Aircraft Guidance/control
10. Vertical guidance, Note 4	Steering, deviation	Nav. system, ATC	P1, P2, autopilot	3	Yes		Aircraft guidance/control
11. Monitor flight progress against filed flight plan	Distance to/passage of waypoints against the clock, fuel remaining	Nav. radios (dist./angle) to/from nav. computer/aeronautical charts, flips, schedule, clock	P2, P1	3	Yes		Navigation
12. General continuous monitoring of flight, nav., engine and aircraft functional systems	Normal (abnormal) operation against limits/flight phase	Displays, operating manuals	P1, P2, S/O, Note 12	2	No		Systems status
13. Alert to failures or unsafe aircraft operation	Failures, Vne & stall warning, unsafe flight modes, conflict, minimum safe altitude	CAWS, GPWS, ATC, and associated displays	P1, P2, S/O	1	Yes		Alerting

PHASE: UBIQUITOUS

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
14. Determine that received information is valid	Information validated	Validity flags, push-to-test results, cross checks of instruments, sta. ident.	P1, P2, S/O	1	No		Verification
15. Maintain knowledge of communication status	Active radio and frequency, preset radio and frequency, last ATC command	Radio controls, flips, previous communication, electronic display	P1, P2, S/O	3	Yes		Systems status
16. Maintain knowledge of operating modes	Systems current operating modes	Pictorial displays, annunciation, switch positions, flags	P1, P2, S/O	2	No		Systems status
17. External environment awareness	Observations, communications, meteorological information, experience	External visual, aural, weather reports, own familiarity	P1, P2, S/O	1 & 3	Yes		External environment
18. Avoid collisions	Hazards to the aircraft	Visual, ATC controller, ATARS, CAS	P1, P2, S/O	1	Yes		Collision avoidance

PHASE: PREFLIGHT

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Briefing to crew	(1) Wx, (2) delays, (3) NOTAMS, (4) special advisories, (5) aircraft status, (6) flt. plan (usually "earned", however, special advisories may require revision.)	Maintenance/dispatcher		4 & 5	Yes		Planning
2. Verify aircraft status	Aircraft maintenance log	P2 summarizes from log	P1 (may also read)	2	No		Systems status
3. Perform walkaround inspection	Security & funct. integrity of A/C	Aircraft itself (visual)	S/O	1	No		Verification
4. Systems checkout	Systems operation - Normal/abnormal	Systems displays and controls	P1, P2, S/O	2	No		Systems status
5. Fuel status	Fuel summary	S/O summarizes (usually "earned" - May require rev. because of available alternates, cargo, pass. load, time of day/traffic)	P1	1	No		Consumables
6. "Seat belts/no smoking" on	Aircraft status	P2 - en. pos.	Cabin	3	No		Advisory
7. Cabin staff briefing	Flight particulars	P1	Staff supervisor	5	No		Advisory
8. Initialize FMS, Note 5	IP, waypoints, destination, energy management parameters	FLIPS or FMS data base	P2 or P1 - initializes system	3	Yes		Systems control
9. Select ATIS, Note 6	Radio/frequency	FLIPS - Jeppesen Approach Charts	P2 - operates	3	Yes		Systems control
10. Request ETIS	DABS D/L data frame	P2	DABS control panel	3	Yes		Systems control
11. Copy ATIS Message, Note 6	Airport & wx. information	ATIS recording	P2 - copies	3	Yes		Communications
12. Receive ETIS message	Airport & wx. information	ETIS	P2 - copies or printout	3	Yes		Communications
13. Select radio for ARTCC clearance delivery (non-DABS aircraft)	Radio/frequency	FLIPS-Jeppesen Approach Charts	P2 - operates	3	Yes		Systems control
14. Contact clearance delivery (DABS aircraft) Note 7	ARTCC clearance request	P2	DABS control panel	1	Yes		Communications
15. Obtain ARTCC clearance (non-DABS aircraft)	Filled flt. plan, transponder code	ARTCC clearance delivery	P2 - copies & obs. against flt. plan	1	Yes		Communications
16. Insert transponder code (non-DABS aircraft)	Assigned code	ARTCC clearance delivery	P2 - sets in code	1	Yes		Systems control

PHASE: PREFLIGHT

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
17. Obtain ARTCC clearance (DMS aircraft) Note 7	Filled flt. plan	ARTCC clearance delivery	P2 - display/printer/ computer memory (cks. against filed flt. plan)	1	Yes		Communications
18. Final crew briefing	Flight plan info, procedures, performance	P2 summarizes	P1, S/O - P1 may specify changes to procedures at that time	3	No		Advisory
19. Signoff manifest/airworthiness/ fuel	Payload Record fuel distribution	Manifest/maintenance record Wt. bal - Flt. plan	P1 - signoff	5	No		Administrative
20. Provide final FMS data	Weight and fuel	S/O	P2 or P1	2	No		Communications
21. Compute takeoff data	V1, Vr, V2, etc.	S/O & P2 compute (wt./bal., airport data), FMS	P1 checks	1	No		Planning
22. Begin preflight checklist	Checklist items	S/O reads	P1, P2, S/O responds	1	No		Systems control/ status
23. Receive cabin report	"Cabin secure"	Cabin supervisor	P1	1	No		Communications
24. Select ground control- radio/freq. Note 7	Radio frequency	FLIPS	P2 - selects	3	Yes		Systems control
25. Request Engine start checklist	Engine start checklist	P1	S/O, P2 Note 12	2	No		Systems control/ propulsion
26. Perform engine start checklist	Initialize systems for engine start	Checklist, displays, controls P2, S/O reads	P1, P2, S/O	1	No		Systems control/ systems status
27. Engine start clearance	"Clear to start!"	P1	Ground controller	3	Yes		Communications
28. Ground engineer clearance	"Clear to Start # ___ engine?"	P1	Ground Engineer	1	No		Communications

*NOTE: All communications to points outside the aircraft requires final acknowledgment from aircraft, even if aircraft originates communications.

PHASE: ENGINE START

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Begin engine start	(1) Air, (2) start valve open, ignition, fuel, etc.	(1) S/O, (2) P1	Engine start controls	2	No		Systems engine preparation
2. Monitor start cycle/verify a stable start NOTE: Generally not more than one engine is started prior to pushback.	Start lt., PP, EPT, oil pressure, hydraulic press, RPM	Respective displays	P1, P2 (monitor & time start), S/O	2	No		Systems status
3. Notify engine systems on line	Air, hyd, electrical	S/O - system displays	P1, P2	2	No		Communications
4. Ground power off	Aircraft power available	S/O	Notify gnd. engr. to disconnect external equipment (bleed air, elec. pwr, air cond.)	2	No		Systems control

PHASE: AFTER ENGINE START

FUNCTIONS IBS						
TASKS	INFORMATION			TOTAL TIME	FUNCTION	
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.	
1. Reconfigure for next engine start	Command to reconfigure	P1	S/O - systems control prep for 2nd start	2	No	Communications
2. Engine log entry	Start time	Engine displays, clock	S/O - enters data	5	No	Administrative
3. Pushback clearance	"Clear to pushback?"	P2	Ground control	3	Yes	Communications
4. Ground Engineer clearance	"Clear to pushback?"	P1	Ground engineer	1	No	Communications
5. Release parking brake/pushback	Brake status	P1	Brake control	1	No	Systems control
6. Pushback complete - reset parking brake	Tug stopped, brake status	P1	Reset parking brake	1	No	Systems control
7. Aircraft log entry	Pushback time	A/C motion, clock	S/O - enters	5	No	Administrative
8. Start # _____ engine	"Parking brake on - clear to start # _____ engine?"	P1	Ground engineer	1	No	Communications
9. Perform after start checklist	per company procedures. Checklist items	S/O reads	P1, P2, S/O respond	1	No	Systems control
10. Clearance from ground crew	"Clear to right/left?"	P1	Ground engineer	1	No	Communications
11. Notify company of pushback time	Plt XII pushback time	S/O	Company	5	No	Administrative
12. Obtain taxi clearance, Note 7	Taxi out clearance request	P2	Ground control	3	Yes	Communications
13. Taxi clearance, Note 7	Clearance and final instructions	Ground control	P1, P2	3	Yes	Communications

PHASE: TAXI OUT

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Energize ix. systems as reqd	Local weather conditions	P1, P2, S/O	Anti-ice/de-ice, cont., windshield heat, wiper, pitot heat, engine inlet heat, etc. Wx. radar to standby.	1	No		Systems control
2. Start taxi out	Parking brake and throttle positions	Brake/throttle controls	P1 - operates	1	No		Aircraft guidance control
3. Check to right/left	No obstacles	External visual	P1, P2	1	No		External environment
4. Select company radio	Radio/frequency	Company procedure	P2 - operates	3	No		System control
5. Nosewheel steering/brakes as required	Aircraft alignment/speed	External visual	P1	1	No		Aircraft guidance control
6. Communicate with company, Note 2	GMT from gate (other, i.e. fuel, etc)	S/O, P2 - clock Note 12	Company	5	No		Communications
7. Fuel system checked and set	NOTE: Every system is checked for operation and then configured for takeoff during the taxi out. Information is conveyed to the Captain by crew intercom. See below example: (1) Fuel boost press.-every pump ck'd and set for T/O (2) All X-feed valves ck'd and set for T/O (3) Wing X-feed valves ck'd and set for T/O (4) All press./flow annunciators ck'd (5) All warning annunciators out	Fuel panel	S/O - reports to P1	2	No		Systems control status
8. Call for taxi checklist	Command	P1	P2, S/O	3	No		Communications
9. Begin taxi checklist	Checklist items	S/O reads	P1, P2, S/O respond	1	No		Systems control status
10. Set flaps/slats for takeoff	Takeoff settings	Flight Manual/checklist	P2 - operates	1	No		Configuration
11. Set stab. trim	Computed setting	S/O - wt. & bal., c.g. cal.	P2, P1	1	No		Configuration
12. Complete taxi checklist	Checklist items	S/O reads	P1, P2, S/O respond	1	No		Systems control status
13. Ground control to tower handoff, Note 7	Contact tower - freq. XXXI Note 7	Ground control, PLIPS	P2, P1	3	Yes		Communications

PHASE: TAXI OUT

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
14. Select radio/frequency [*] [*] Not required when DMS frequency tuning is available.	Radio/Frequency	FLIPS, Ground controller	P2 - selects	3	Yes		Systems control
15. Contact tower	Aircraft identity	P2	Tower controller	3	Yes		Communications
16. Tower to aircraft comm. Note 7	Runway lineup instructions	Tower controller	P1, P2	3	Yes		Communications
17. Stop aircraft in holding area	Arrival in line	External visual	P1 aircraft brakes	3	Yes		Aircraft guidance control
18. Call for before takeoff checklist	Command	P1	P2, S/O	3	No		Communications
19. Complete before takeoff checklist (off active runway)	Initialization for takeoff	S/O reads	P1, P2, S/O respond	1	No		Systems control status
20. Final takeoff/abort procedure, briefing	Procedures review	P1	P2, S/O	1	No		Advisory
21. Notify flight attendants of impending takeoff	Be seated	P1, P2, or SO and PA	Flight attendants and passengers	3	No		Communications

PHASE: TAKEOFF & CLIMB

FUNCTIONS 1B5

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
1. Receive tower controller message, Note 7	Clear for takeoff	Tower controller	P1, P2, S/O	1 & 3	Yes		Communications
2. Taxi onto runway and align A/C with C/L	Position relative to runway	External visual	P1, P2	1	Yes		Aircraft guidance control
3. Complete lineup checklist	Checklist items initialized after taking active runway	S/O - reads 1985, P2 1990-1995	P1, P2, S/O respond, Note 12	1	No		Systems control, status
4. Start takeoff	"Takeoff thrust" command	P1	S/O or P2	1	No		Communications
5. Advance throttle	Throttle position	Internal visual, engine primary power ind.	P2, P1	2	No		Systems control
6. Monitor engine/flight instruments	After throttle advances and before V1 workload and stress is high. Usually 7/6 power should be available in about 5 seconds; then, in 15-20 secs., the following must be checked: (1) EPR set and stable at target thrust (2) RPM within limits on each engine - acceleration normal and stable (3) EGT acceleration normal and within limits (4) Oil press. within limits (5) Oil temp. within limits (6) Fuel flow - normal limits (7) Hyd. press. - within limits (8) All warning ann. - out (9) Airspeed increasing and cross-checked (10) Aircraft acceleration normal as compared to calculations, i.e., (30 kts in 22 sec) (11) The entire "thought process" is alerted to stop "Takeoff thrust"	Engine and system displays	P1, P2, S/O	1 & 2	No		Systems status
7. Takeoff thrust verification		P2	P1, S/O	2	No		Communications, advisory
8. Maintain aircraft alignment with runway	Runway heading, crosswind, aircraft heading	External visual	P1 - nosewheel steering	1	No		Aircraft guidance control
9. Maintain wings level	Roll attitude	Attitude display/visual	P2 - control wheel	1	No		Aircraft guidance control
10. Monitor engine instruments	EPR, RPM, FF, EGT	Engine displays	S/O	2	No		Systems status

PHASE: TAKEOFF & CLIMB

FUNCTIONS 1BS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
11. Announce speed	Rudder effective speed	P2	P1	2	No		Communications
12. Transition to rudder steering	Speed sufficient for rudder control	P2	P1 - changes to rudder control	1	No		Aircraft control
13. Announce critical engine failure speed NOTE: P1 now mentally transitions to fly and to airborne emergency procedures.	"V ₁ "	P2	P1	1	No		Communications
14. Announce rotate speed	"VR"	P2	P1	1	No		Communications
15. Rotate aircraft to takeoff attitude	Rotate speed reached	P1 - pulls back on column (still headup)	Pitch attitude	1	No		Aircraft control
16. Announce positive rate of climb	"Positive rate"	P2	P1	1	No		Communications
17. Gear up callout NOTE: (1) S/O now usually transitions back to his station (2) P2 usually transitions to heading checks for traffic right/left and handles communications.	"Gear up"	P1	P2	1	No		Communications
18. Raise landing gear	Command	P2	Gear handle	1	No		Communications, S/O, cockpit
19. Monitor airspeed thrust, acceleration, for V2	Airspeed, EPR	EPR, airspeed displays	P1	1	No		System status
20. Call V2 speed	V2 speed	P2	P1, S/O	2	No		Communications, cockpit
21. Hold V2 speed NOTE: Hold V2 speed until clear of obstacles, clear of noise abatement procedures, or 400 ft. (whichever is greater) and all engines are O.K.	Airspeed thrust, vertical velocity, altitude	P1	Throttle, pitch controls	1	No		Aircraft control
22. Log takeoff time	Date, takeoff time	Liftoff, clock, calendar	S/O - aircraft log	5	No		Administrative
23. Accelerate/maintain positive rate of climb	Thrust, airspeed, pitch attitude, V/V	EPR, airspeed displays, ADI, V/V	P1	1	No		Aircraft control
24. Turn off "no smoking" signal	Smoking permitted	P1	P2, cabin	3	No		Communications and advisory

PHASE: TAKEOFF & CLIMB

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
25. Flap callout	"Flaps ____ position"	P1	P2	1	No		Communications
26. Begin flap retraction	Command	P2	Flap handle	1 & 2	No		Communications
27. Notify company - time off Note B	GNT off the runway	S/O - clock	Company	5	No		Communications
28. Tower/Departure Control Hardoff, Note 7	"Contact Departure Cont. - freq. xxxx"	Tower Controller	P2, P1, S/O	3	Yes		Communications
29. Select radio/frequency* *Not required when DABS frequency tuning is available.	Radio/frequency	Tower	P2 - selects	3	Yes		Systems control
30. Continue flap retr. cycle*	"Flaps"	P1	P2	1	No		Communications
*Flap retraction cycle continues as a function of airspeed until flaps are up and S/O verifies slats are stowed. NOTE: May be automated in PWS in 1920's.							
31. Turn off "seat belts"	"Seat belt" signal extinguished	P1	P2 - cabin	3	No		Communications and advisory
32. Contact departure control	Aircraft identity & assigned altitude	P2	Departure controller	3	Yes		Communications
33. Rec. departure instructions Note 7	(SID clearance or vectoring)	Departure Controller	P1, P2	3	Yes		Communications
34. Initiate "after takeoff/climb checklist"	Checklist items	P1 commands	P2 & S/O	1	No		Communications
35. Complete after takeoff/climb checklist	Checklist items	S/O reads checklist	P1, P2, S/O respond	1	No		Systems control/status
36. Contact company*, Note 8 *This is a continuing function covering items such as: checkpoint crossing, next checkpoint ETA, needed maintenance, fuel usage, needed fuel, SELCAL, etc.	See note below	Nav & f/t displays, FWS, S/O	Company	5	No		Communications
37. Select desired hdg/Select flt director mode	Departure hdg.	Dept. controller	P1 - operates	2	Yes		Systems control
38. Select V3 mode/assigned altitude	Mode, altitude	Company proc.	P1 - operates	2	No		Systems control

FUNCTIONS IBS

PHASE: TAKEOFF & CLIMB

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
39. Engage autopilot NOTE: (1) FWS automatically captures/holds 250 Kts IAS. (2) At this point, P1 may or may not replace heading with LNAV. If there are avoidable thunderclouds, he'll stay on hdg and request a deviation from ATC. (LNAV would just provide guidance from the stored dtd.)	A/P status	Company proc. & P1	P1, A/P control	2	No		Systems control
40. Engage autothrottle	Autothrottle	P1 company proc.	Autothrottles cont.	2	No		Systems control
41. Engage flight mgt. sys. NOTE: FWS automatically captures/holds 250 Kts IAS below 10000', then left IAS.	Control status	Manual	P1 - selects	2	No		Systems control
42. Confirm arriving at checkpoints	Checkpt. arrival - ETA next checkpoint	P2	P1, flight log	3	No		Communications, and in.
43. Monitor climb/level off - intermediate altitude	Thrust, acceleration, airspeed, altitude, attitude	Flt/engine inst.	P1	2	Yes		Aircraft attitude control
44. Departure/enroute handoff Note 7	*Contact enroute control - freq. xxxx	Departure controller	P2	3	Yes		Communications
45. Rec. and confirm altitude clearances, Note 7	Clearance instructions	ATCC	P2	3	Yes		Communications
46. Notify ATC leaving intermediate altitude Note 9	Aircraft identity - "leaving altitude"	P2 - FWS/aircraft alt.	ATC	3	Yes		Communications
47. Man. accel. to climb IAS NOTE: As IAS approaches climb IAS (320 Kts. for ex.), the FWS gently pitches up the aircraft to continue the climb, holding 320 Kts. on pitch. If VS falls below limits, the FWS increases thrust automatically.	IAS	IAS display	P1	2	No		Aircraft attitude control
48. Select radio/frequency* *Not required when DABS frequency tuning is available.	Radio/frequency	ATCC	P2 - selects	3	Yes		Systems control
49. Contact enroute control	Aircraft identity	P2	ATCC	3	Yes		Communications
50. Enter log data	Event times, fuel usage, needed maintenance, etc.	Intercom, displays, malfunction info.	S/O - enters log data	5	No		Administrative

PHASE: TAKEOFF & CLIMB

FUNCTIONS IBS

TASKS	INFORMATION				TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS		
<p>51. Reset altimeters to std. baro</p> <p>NOTE: Climb at IAS until climb mach is reached, then at mach.</p> <p>Transition to Cruise - As the aircraft nears the assigned cruise altitude, which has been preselected on the altitude select panel and entered into the FMS, the FMS noses the aircraft over gently and gradually accelerates (or decelerates) to the desired cruise mach no. Throttle control transitions from climb thrust to cruise per. Short-term speed corrections are in pitch, trading small altitude changes for speed (usually ± 40 ft.). Longer-term changes are made by throttle.</p>	Std. baro	Passing through 18,000 ft.	P1, P2 reset	1	Yes	System control

PHASE: CRUISE

TASKS		INFORMATION					TOTAL TIME	FUNCTION
		CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Notify ATC - reached cruise alt.		Assigned altitude reached	P2 or P1	ARTCC	3	Yes	Communications	
2. Request cruise checklist		Cruise checklist	P1	S/O, P2, Note 12	4	No	Communications	
3. Execute cruise checklist		Cruise checklist	S/O, P2, Note 12	P1, P2, S/O	3	No	System's status state	
NOTE: Com. radio frequency selection workload in cruise is dependent upon route and altitude. Frequency selection workload is eliminated for ATC communications when DAB's data link service is available and aircraft have the service implemented.								
4. Monitor wx radar		Wx cells	Radar display	P1, P2	2	Yes	External environment	
5. Receive wx info. Note 7		Wx along flt. path	Company, ATC, Radar	P1, P2, S/O	1	Yes	Communications	
6. PR message to passengers		Welcome - gen. flight info	P1 or designee	Passengers	3	No	Advisory	
7. Interrogate FMS for optimum altitude		Interrogation - current wind/temperature conditions	FMS	P1 or P2 - Opr. FMS	2	No	Planning	
8. Obtain FMS Alt. chg. info.		Opt. alt. (favorable)	FMS	P1, P2	3	No	Planning	
9. Request altitude change		Request clearance to FL XXX	P1	P2	3	No	Communications	
10. Altitude change request		A/C identity, request clearance FL XXX	P2	ARTCC	3	Yes	Communications	
11. Rec. ARTC clearance		A/C identity - cleared FL XXX	ARTCC controller	P1, P2	3	Yes	Communications	
12. Select new alt. - FMS		"FL XXX," TTY	Previous planning	P1 - Alt. select panel ARTCC controller	2	No	Systems control	
13. Notify ATC leaving FL XXI, Note 9		A/C ident, leaving FL XXI for FL XXX	P2		3	Yes	Communications	
14. Monitor climb		EPR, vert. vel., mach, altitude	Flt. & Eng. displays	P1, P2	2	Yes	Aircraft guidance control	
NOTE: After new alt. is selected, the FMS automatically initiates the climb maneuver and capture of the altitude.								
15. Notify ATC at FL XXI, Note 9		A/C Ident. - at FL XXX	P2 - altimeter	ARTCC controller	3	Yes	Communications	
NOTE: In the Tristar, the FMS mixes all available nav. sensors to automatically arrive at the best refined aircraft position (Gnd. spd., etc.). The optimal mix (or mode) is chosen automatically based on what sensors are available; as this availability changes, modes are degraded or upgraded accordingly. These modes are in order of best on down: DME/DME with or without inertial (1, 2, or 3 inertials) VOR/DME " " Inertial only (1, 2, or 3 inertials) Dead reckoning (using hdg., TAS, and best winds).								

PHASE: CRUISE/DESCENT TRANSITION

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
1. Select ATIS, Note 6	Radio/frequency	Jeppesen Approach Charts	P2 - selects	3	Yes		Systems control
2. Receive ATIS msg., Note 6	Airport, wx. info	ATIS recording	P2 copies, P1 listens, S/O	3	Yes		Communications
3. Request ETIS	DARS "canned msg."	DARS data bank	P2 - transmits	3	Yes		Communications
4. Receive ETIS	Airport, weather info	ETIS	P2 - visual, cptr. memory, printout	3	Yes		Communications
5. Insert ATIS/ETIS info into FCS	Airport wx conditions (temp., press alt., wind)	P2	FMS	3	No		Planning
6. Review approach procedures	Approach plates	Jeppesen Approach Charts	P1, P2	3	Yes		Planning
7. Call for descent checklist	Descent checklist	P1	S/O, P2 Note 12	3	No		Communications
8. Set aircraft systems for descent	(1) ECS (Environmental Control System) (2) Fuel system (3) Electrical system (4) Hydraulic system	(1) S/O, P2 (2) S/O (3) S/O (4) P2	(1) S/O monitors temp & press; P2 sets airport alt (2) S/O sets for landing (3) S/O sets for landing (4) P2 checks	1	No		Systems control
9. Complete descent checklist	Checklist items	S/O - reads	P1, P2, S/O - execute	1	No		Systems control/status
10. Monitor time to begin descent point	Time to D+D	FMS	P1	2	Yes		Planning
11. Request descent clearance, Note 7	Request clearance to begin descent in _____ minutes	P1 - FMS	ARTCC controller	3	Yes		Communications
12. Rec. clearance to descend, Note 7	ATC clearance	ARTCC controller	P1	3	Yes		Communications

PHASE: DESCENT

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Set altimeters to field baro. <u>NOTE 15:</u> The FMS will automatically nose over the aircraft at the E/D point, reduce power, and acquire the desired mach no. for descent. A prediction is made whether the aircraft is descending long or short of the optimized spatial profile. Throttles are held in idle and speed is controlled by pitch all automatically. As airspeed reduces (during the mach hold descent) to nearly the desired airspeed, the FMS switches to an IAS hold mode, at 10,000 ft., the FMS levels off the aircraft for deceleration to 250 Kts., then pitches over to hold 250 Kts. IAS until E/D altitude is reached. At E/D altitude, the FMS again levels the aircraft off as E/D is overflown at the correct speed and altitude (and time if 4-D is used).	Field baro.	ATIS/STIS, ARTC	P1, P2	2			Systems control
<u>NOTE:</u> Reports to ARTC controller are made to report arriving/leaving cleared altitudes.							
2. Request desired STAR, Note 7 Aircraft identity request _____ arrival		P1 or P2 - Jeppesen Charts (stored in FMS)	ATC controller	3	Yes		Communications
3. STAR clearance, Note 7 Aircraft identify, "cleared _____" ARTC controller			P1, P2	3	Yes		Communications
4. Set cleared alt. into ALT. SEL, P/L & ARM Cleared altitude		ARTCC controller	P2 or P1	2	Yes		Systems control
<u>NOTE:</u> P1 or P2 continue to get clearances to lower altitudes far enough in advance so that aircraft is never forced to level off.							
5. Calculate VREF & GA thrust settings VREF, EPR, GA EPR		FMS, 3/0 cross checks, Note 15	P1, P2 - Ck.	1	No		Planning
6. Set VREF & EPR bugs VREF, EPR settings		P1, P2	Bugs/displays	1	No		Systems control
7. Monitor wx radar Storm cells		Radar display	P1, P2	2	No		Weather information
8. Request deviation for Wx Change heading to miss Wx		P1	P2	3	No		Communications
9. Contact ATC controller, Note 7 Diversion for wx request		P2	ATC controller	3	Yes		Communications
10. Execute wx diversion maneuver Turn aircraft to new heading		P1	Autopilot	1	Yes		Aircraft guidance control
11. Rec. vectoring instructions-traffic avoidance, Note 11 Headings, speed, altitude		ARTCC controller	P1, P2	3	Yes		Communications
12. Execute vectoring instructions* * Hdg., speed, altitude - from ATC		P1	Fit & speed controls	1	Yes		Aircraft guidance control
* Includes holding patterns when required.							
13. ARTCC to approach control handoff*	Aircraft identity, "Contact approach control," freq. _____	ARTCC	P1, P2	3	Yes		Communications

* Co communications not required when DABS implemented.

PHASE: APPROACH/LAND

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
1. Set approach speed + 30 Note 15	Approach speed + 30	PWS, S/O, P2	P1, P2	3	No		Aircraft guidance control
2. Request initial slat/flap	Slat/flaps setting	P1	P2	1	No		Communications
3. Increment slat/flap position	Slat/flaps setting	P2	Slat/flap control handle	1	No		Configuration
4. Verify slat/flap config.	Slat/flap position	P2	P1	2	No		Verification
5. Mon. speed and request next flap setting	Airspeed and flap setting	P1	P2	1	No		System status & communications
6. Change airspeed to approach speed + 20K. Note 15	Approach speed + 20K.	P1	Throttles	1	No		Aircraft guidance control
7. Receive radar vectoring, Note 11	Aircraft heading	Approach control	P1, P2	3	Yes		Communications
8. Execute Vectoring instructions	Turn to new heading	P1	Autopilot	1	Yes		Aircraft guidance control
9. Request approach/checklist	Checklist	P1	S/O	3	No		Communications
10. Execute approach/checklist	Approach checklist items	S/O - reads	P1, P2, S/O execute	1	No		Systems control
11. Tune nav radios for approach, Note 15	Radio/frequency	Jeppesen Chart	P2 - tune	3	No		Systems control
12. Select MLS receiver channel (MLS equipped aircraft) Note 14	Airport MLS channel	Jeppesen Chart	P1, P2	3	Yes		Systems control
NOTE: Azimuth and elevation angles are specified in STAR and are stored in FMC.							
13. Receive final vector instructions, Note 11	Final heading and altitude to intercept ILS or MLS	Appr. Cont.	P2, P1	3	Yes		Communications
14. Select approach mode on autopilots	Mode status	P1 or P2	Autopilot cont. pul.	Sup. Mgt.	No		Systems control
15. Verify LOC ARM, O-S ARM	Status	Annunciators	P1 & P2	3	No		Systems Status
16. Call for lng. gear down	Command	P1	P2	1	No		Communications
17. Lower landing gear	Gear position	Command	P2 - gear handle	1	No		Configuration

PHASE: APPROACH/LAND

TASKS		FUNCTIONS IBS				
		CONTENT		INFORMATION		
		SOURCE		DESTINATION	CLASS	ATC SENS
18. Lower landing gear		Gear position	Command	P2 - gear handle	1	No
19. Check lng. gear down		Gear position	Pos. indicators	P2, P1	1	No
20. Call for before landing/ checklist		Command	P1	P2, S/O	1	No
21. Acknowledge LOC/capture achieved (replacing previous lateral steering modes)		LOC capture	Annunciators and displays	P1	1	No
22. Select AUTOLAND mode		Mode status	P1		1	No
23. Change airspeed to app. speed + 10 K		App. speed + 10 K	P1	Mode selector	2	No
24. Select landing flaps		Flap pos.	P1	Throttles	1	No
25. Change airspeed to approach speed, Note 15		Approach speed	P2	Flap control	1	No
26. Acknowledge glide slope capture		Glide slope capture	P1	Throttles	1	No
27. Approach control/tower handoff		Tower freq.	Annunciators and displays	P1	1	No
28. Select radio/freq.		Radio/freq.	Approach control	P1, P2	1	No
29. Note position over final approach fix		Fix passage	Appro. control	3	Yes	Yes
30. Contact tower		Aircraft ident, position	Annunciators	P2 - selects	3	Yes
31. Verify ATS is in angle of attack mode		ATS status	P2 or P1	P1, P2	1	Yes
32. Monitor LOC/GS tracking and airspeed		Deviation, airspeed	Annunciator	Controller	3	Yes
33. Announce runway in sight (if he can see)		Location of runway	Displays	P1	1	No
34. Verify A/L mode achieved		"Align ARM," "Flare ARM"	P2	P1, P2	2	No
35. Verify no A/L faults annunciated prior 150 ft.		No annunciation	A/C display	P1, S/O, tower	1	Yes
			Annunciator panel	P1, P2	1	No
				P2, P1	1	No
						Verification
						Verification

PHASE: APPROACH/LAND

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
36. Call 100' above DH	Altitude	P2 - radio altimeter	P1	1	No		Communications
37. Call "Land" or "go around"	Decision Height	P2	P1	1	No		Communications
38. Verify PLANE at 50 ft RA	Aircraft attitude	Display - visual	P2	1	No		Verification
39. Assure ATS retards throttles to idle and disconnects	Throttle pos.	P1	Throttles	1	No		Verification
40. Verify rollout mode at 5 ft RA (assume landing)	Mode status	Annunciators	P1, P2	1	No		Verification
41. Observe landing	Touchdown	Visual	P1	1	No		Aircraft guidance control
42. Monitor spoiler deployment	Spoiler pos.	Pos. indicator	P2	1	No		Confirmation
43. Headup monitor runway centerline guidance if runway not in sight - available 1995	Deviation beam runway centerline	Display	P1	1	No		Verification
44. Select reverse thrust	Throttle pos.	P1	Throttles	1	No		Systems control
45. Call nosewheel steering speed	Speed	P2	P1 - transitions to nosewheel steering	1	No		Communications
46. Throttles to 0nd Idle	Throttle pos.	P1	Throttles	1	No		Systems control
47. Disconnect autopilot	Autopilot status	P1	Autopilot cont	2	No		Systems control
48. Brake to exit spd or stop	Speed	P1	Brake pedals	1	No		Aircraft guidance control
49. Rec. exit instructions from tower	Instructions	Tower	P2, P1	1 & 3	Yes		Communications
50. Exit runway	Turnoff/aircraft pos.	P1 - visual	Nosewheel steering	1	Yes		Aircraft guidance control
51. Contact Ground Control and receive taxi instructions	A/C identity and instructions	Ground control	P2, P1	3	Yes		Communications
52. Tune Ground Control freq.	Radio freq.	Flaps or tower	P2, radio	3	Yes		Systems control

PHASE: TAXI IN

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
1. Call for after landing checklist	Command	P1	S/O	3	No		Communications
2. Execute after landing checklist	Checklist items	S/O - calls	P1, P2, S/O - executes	1	No		Systems control at the
3. Control aircraft (taxi)	Speed, direction	P1	Throttles, nose wheel steering	1	Yes		Aircraft position control
4. Watch for ground traffic	Obstacles	External visual	P1, P2	1	Yes		External environment
5. Select company ramp radio	Radio/frequency	Company procedures	P2 - selects	3	No		Systems control
6. Obtain gate assignment/taxi instructions	Gate assignment/instructions request	S/O or P2, Note 12	Ramp control	3	No		Communications
7. Transition to APU power [*]	APU startup procedures	P1	APU/electrical system controls	2	No		Systems control
[*] Usually an engine or two is shut down here after APU is up and running.							
8. Brake to stop at gate	Ground marshaller guidance	Positioning marshaller or guidance device	P1 - stops aircraft	1	No		Aircraft position control
9. Set parking brake	Brake status	P1	Brake control	1	No		Systems control
10. Contact tug operator/ground engineer [*]	Tow request	P1	Tug operator	3	No		Communications
[*] At some airports, the aircraft must be towed in.							
11. Release parking brake	Brake status	Cmd. engr. request	P1 - releases brake	1	No		Systems control
12. Set parking brake	Brake status	Cmd. engr. request	P1 - sets brake	1	No		Systems control
13. Transition to ground power if desired	A/C parked, ground power desired	S/O	Ground power control	2	No		Systems control
14. Shut down engines	Engine control status	P1, P2, S/O	Engine controls	2	No		Systems control
15. Accomplish shutdown checklist	Checklist items	S/O calls	P1, P2, S/O	1	No		Systems control, systems status
16. Complete maintenance log	Condition of aircraft	S/O or AIDS	Log	5	No		Administrative
17. Debriefing (crew reporting area)	Trip report	P1, P2, S/O	Company	5	No		Communications

PHASE: COMPANY REPORT ITEMS (TYP.) - SUPPLEMENTARY INFORMATION

FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. SERICAL	Alert signal	Annunciator	S/O, P2, P1	5	No		Communications, Alert
2. Company report	Fuel usage/needed fuel	S/O	Company	5	No		Communications
3. Company report, Note 8	Checkpoint crossing/next checkpoint ETA	S/O	Company	5	No		Communications
4. Company report	Needed maintenance	S/O - transmits	Company	5	No		Communications

PHASE: CABIN COMMUNICATION ITEMS (TYP.) - SUPPLEMENTARY INFORMATION FUNCTIONS IBS

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS.		
1. Contact cabin flight attendant	Request for coffee/meals	S/O	Cabin staff	5	No		Communications
2. Contact cabin flight attendant	Temperature adjust/report	S/O	Cabin staff	2	No		Communications
3. Contact cabin flight attendant	Chime signals (turbulence, descent, etc.)	P2	Cabin staff and passengers	4	No		Communications

FUNCTIONS IBS

PHASE: ATC COMMUNICATIONS ITEMS (TYP.) - SUPPLEMENTARY INFORMATION

TASKS	INFORMATION					TOTAL TIME	FUNCTION
	CONTENT	SOURCE	DESTINATION	CLASS	ATC SENS		
1. Contact ARTC	Advise of winds aloft	P2	ARTC controller	3	Yes		ADVISE WINDS ALOFT
2. Contact ATC	Request direct flight clearance	P1 - PMS	ARTCC	3	Yes		COMMUNICATIONS
3. Contact Wx Advisory service	Request winds aloft	P2	Wx service	4	No		COMMUNICATIONS
4. Record ARTC message	CAT or other unusual conditions	ARTC controller	P1, P2	1	Yes		COMMUNICATIONS
5. Contact ARTC	Advise of CAT or other unusual conditions	P2	ARTC controller	1	Yes		COMMUNICATIONS
6. Record ATC message	Traffic advisory	ATC controller	P2, P1	1	Yes		COMMUNICATIONS

**TECHNOLOGY
WORKSHEETS**

1. TITLE: MICROWAVE LANDING SYSTEM (MLS)

2. IMPLEMENTATION SCHEDULE:

Service Test - 1981 - 1984

Initial Operational Use - 1985

3. DESCRIPTION: The Microwave Landing System is a C-band time-referenced scanning beam system providing azimuth coverage of up to plus or minus 60 degrees and elevation coverage of 20 degrees with distance information provided by a co-located DME. Information from these beams and the DME enable equipped aircraft to determine their position relative to the touchdown point by means of on-board equipment.

MLS will provide a much more flexible approach guidance technique which may be tailored to the particular airport, traffic situation and aircraft. The frequencies selected result in smaller antennas and fewer problems from terrain reflections. This and the curved approach capability will make installation practical for many runways where ILS has not been feasible. Many runways are restricted to visual approach now because of obstacles, noise abatement procedures or traffic pattern interference with other airports.

Initial purchases of airborne equipment are expected to be for commuter aircraft with routes into airports with such special problems. One such situation exists at Washington National 18, where MLS has recently placed in service for operational evaluation. JFK 13L and Newark 11 are similarly restricted. Current plans are for approximately ten ground systems to be operational by 1985. Perhaps 1200 MLS ground systems may be operational by 2000.

MLS receivers are estimated to cost under \$2,000 for general aviation aircraft and \$6,000 for airlines.

4. OPERATING SCENARIO: Upon entry into the terminal area, ATC would assign the aircraft an MLS approach path consistent with its approach direction probably uplinked through DABS or the MLS data link. The path could be a conventional straight, shallow approach similar to ILS or it could be a steep, curved approach to reduce noise or avoid obstacles. Autoland will probably be the normal MLS operating mode.

5. INPUT INFORMATION:

Channel selection (DME & MLS)

Approach path designation

6. OUTPUT INFORMATION:

Approach guidance or monitoring.

Path definition.
System considerations.
Terminal information.

7. INPUT REQUIREMENTS: Alpha-numeric selection input. Possible DABS uplink of curved or segmented approach path data or recall from stored data.

8. INPUT OPTIONS: Keypad, thumbwheel switches, DABS uplink automatic, semi-automatic or manual entry, menu select from prestored (FMS) data, FMS keypad.

9. OUTPUT REQUIREMENTS: Analog guidance commands (similar to ILS), graphic display of present position and path would be desirable, alpha-numeric display for system and terminal information. Steep, curved approaches may require elaborate graphics presentations.

10. OUTPUT OPTIONS: EADI, EHSI, Weather Radar Display, conventional ADI, HSI, Multifunction Display, FMS Display for alpha-numeric.

11. TIME OF USE: During approach and possibly climbout.

12. WORKLOAD IMPACT: Little effect, slight reduction for approach entry.

13. DISCUSSION: Initially aircraft will probably use only straight-in approaches similar to today's ILS. Current ADI type display will suffice for this purpose. Since much greater proportional guidance is available, additional instrumentation would aid in acquisition however.

General aviation, commuters and STOL aircraft may elect to use steeper, curved or segmented approaches for short finals or limited access runways. For this application a more sophisticated display approach will probably be required, especially if manual control is to be considered. It is generally agreed that some form of predictor display is necessary for three dimensional path tracking.

Many MLS approaches will be autoland controlled. In such cases the display should be optimized for monitoring, with go-around being the standard procedure in the event of approach abort.

Requirements may arise to integrate DABS information with MLS data if terminal navigation and tailored approaches for individual aircraft are considered.

Functional and philosophical considerations need to be resolved regarding interface between MLS, FMS, RNAV, and ILS. In addition the impact of ATARS, BCAS, GPS and CDTI should be considered.

1. TITLE: DISCRETE ADDRESS BEACON SYSTEM (DABS)
2. IMPLEMENTATION SCHEDULE:
Service Test - 1984

Operational - 1988

3. DESCRIPTION: The Discrete Address Beacon System, in addition to its surveillance function in the ATC system, has an associated data link function available for ground-to-air and air-to-ground communications. While it is recognized that the information services are in the early stages of definition and are not yet firm, a look at the current candidates is in order to examine cockpit impact.

DABS production sensor deliveries are scheduled to begin during 1984. DABS transponder deliveries (Collins for Boeing 767) will begin in late 1981. Manufacturers currently plan to offer basic DABS transponders with provisions for later addition of data link and BCAS capability.

A DABS transponder is estimated to cost from \$2,000 for a general aviation aircraft application to \$15,000 for an airliner.

4. OPERATING SCENARIO: Basic DABS will perform much like the presently used ATCRBS as far as the Flight crew is concerned.

5. INPUT INFORMATION: Service requests, clearance acknowledgements, output selection (printer, display), clear display.

6. OUTPUT INFORMATION: ATC clearances, warnings, weather and terminal information metering and spacing instructions.

7. INPUT REQUIREMENTS: Alpha-numeric input or message selection w' data entry as required.

8. INPUT OPTIONS: FMS keyset, ACARS keyset, dedicated or portable touch panel or display labeled switches for message selection.

9. OUTPUT REQUIREMENTS: Text and graphics.

10 OUTPUT OPTIONS: FMS display, multifunction display, weather radar displ. or printer for text. LCD strips adjacent to ADI or integrate with EADI for clearances.

11. TIME OF USE:

Uplink - Tactical messages at ATC option anytime.
Other information, as requested by flight crew.

Downlink - Service requests at flight crew option.

12. WORKLOAD IMPACT: Little effect, acknowledgement effort is offset by reduced note taking and verbal confirmation. Later services such as radio channel switching may considerably reduce workload.

13. DISCUSSION: I/O requirements vary with message type and direction.

Downlink messages

Flight crew generated messages will normally be composed by filling in blanks

in pre-designated forms retrieved from computer memory. A multi-line text display, perhaps 40 characters, should be adequate for the downlink scratch pads. Some form of alpha-numeric keyset will be necessary.

Uplink Messages

Tactical message - Short, require immediate attention of crew. Ideally, should be displayed on or adjacent to the flight instruments. Consider individual displays for last assigned altitude, airspeed, heading and radio channel. Aural alert probably desirable for changes. Consider storage of pertinent previous messages (for example, last radio channel).

Information messages - Longer, generally result from crew request. Could be printed out or displayed on a multifunction display. If not printed, may require storage for later retrieval if displaced by a higher priority function. Information could be updated by DABS in memory without display until requested by crew. Many display techniques are possible for specific data (example - weather map) depending on equipment available. Standard uplinked data could be reformatted on board the aircraft for raster scan weather radar, ACARS printers, flight management displays, alpha-numeric liquid crystal display panels, etc.

A selectable text to voice output might be desirable under some conditions (backup system, low cost general aviation, one man cockpits).

1. TITLE: DABS DATA LINK - TAKEOFF CLEARANCE CONFIRMATION
2. DESCRIPTION: This is an uplink message that confirms the takeoff clearance issued orally from the tower over voice communications. Example of typical message: "TAKEOFF 9R".

1. TITLE: DABS DATA LINK - ALTITUDE ASSIGNMENT CONFIRMATION
2. DESCRIPTION: This is an uplink message to provide confirmation of current voice delivered altitude clearances. The three messages involved are: (1) "MNTN ---," (2) "CTAM FL ---," (3) "DTAM ---" for instruction to maintain an altitude, climb to and maintain an altitude or descend to and maintain an altitude, respectively.

1. TITLE: DABS DATA LINK - MINIMUM SAFE ALTITUDE WARNING
2. DESCRIPTION: This is an automatic uplink message forwarded to an aircraft when the aircraft is about to or has dropped below a minimum safe altitude. This is a backup to the current voice warning delivered by controllers. Two messages are involved: "MSAW" alert is transmitted whenever the above condition exists. "MSAW CLR" when the aircraft climbs above the minimum safe altitude.

1. TITLE: DABS DATA LINK - ENHANCED TERMINAL INFORMATION SERVICE

2. DESCRIPTION: ETIS will be an improved ATIS. Information on weather, visibility, RVR, winds, runway in use, altimeter, and similar services pertaining to the airport will be provided. Requests for ETIS originate from the aircraft and a choice of automatic updates is available.

1. TITLE: DABS DATA LINK - WEATHER

2. DESCRIPTION: The data link provides an alternate means for receiving weather information to that currently received by voice. Requests originate in the cockpit. Some of the services now planned are:

- (1) Surface observations
- (2) Terminal forecasts
- (3) PIREPS
- (4) Hazardous weather advisories
- (5) Digitized weather radar maps
- (6) Winds aloft

Current plans are to offer the above through menu selection.

1. TITLE: DABS DATA LINK - METERING AND SPACING COMMANDS

2. DESCRIPTION: Metering and spacing commands are used to de-randomize air traffic and get the traffic spaced in trail for final approach and landing. Currently, metering and spacing is accomplished by use of holding patterns path stretching, turns, etc. to get aircraft into the desired time/spatial relationship. Vectoring commands for airspeed, altitude, and heading changes are currently transferred to an aircraft by voice. Eventually, M&S will be done automatically by ground computers with commands communicated to an aircraft over DABS.

1. TITLE: DABS DATA LINK - CLEARANCE DELIVERY

2. DESCRIPTION: Clearance delivery is currently obtained by voice communications. The approved flight plan is copied by a crew member and is compared to the filed flight plan for any changes. This function has been proposed as a DABS data link candidate.

1. TITLE: DABS DATA LINK - VOICE RADIO TUNING

2. DESCRIPTION: The subject of automatic tuning of aircraft radios for ATC voice communications by means of DABS message has been suggested. Because of the many voice contacts an aircraft makes with ATC facilities during a flight, tuning of VHF radios is a significant workload in the cockpit.

1. TITLE: DABS DATA LINK - DOWNLINK OF AIRCRAFT INFO

2. DESCRIPTION: One of the uses being considered for DABS is the downlinking of information from airborne sensors. Such information as turn indication, winds aloft, turbulence, or other weather information would be useful additions of information to the ATC system.

1. TITLE: DABS DATA LINK -ATARS

2. IMPLEMENTATION SCHEDULE:

- (a) Service Test - 1984 (1st Site Commissioned)
 - (b) Regular Opr. - 1988 (120th Site Commissioned 1987)
- FAA Washington Data

3. DESCRIPTION: The automatic traffic advisory and resolution service is a pilot-oriented ground-based collision avoidance system. The system uses DABS surveillance information and computes traffic and resolution advisories which are sent to ATARS equipped aircraft via the DABS data link. The system is backup to, and independent of, the current controller/computer separation assurance system which communicates to an aircraft over voice links.

ATARS uses DABS data link for transmission to the aircraft and is dependent on the start of DABS operation. Further investigation of the above dates is needed - should be verified from airline sources.

4. OPERATING SCENARIO: System operation is a minor consideration; however, the display of ATARS information will be an attention magnet to the pilots, especially in congested traffic situations.

ATARS Advisory -

5. INPUT INFORMATION: Possibly range or scale selection, request for projected relative position, option to activate or suppress. Advisory function.

6. OUTPUT INFORMATION: Relative position of proximate aircraft. Time and position of projected minimum separation. Other aircraft descriptive data. (bearing, altitude, range, heading, velocity, control status, and ATARS equipment).

7. INPUT REQUIREMENT: Alpha-numeric or menu selection.

8. INPUT OPTIONS: Display labeled switches or menu item select through multifunction display and keyset, FMS display and keyset or dedicated panel.

9. OUTPUT REQUIREMENT: Alerting signal and graphical display of positions with alpha numeric and/or symbolic descriptive data preferable.

10. OUTPUT OPTIONS: Alerting tone or voice, integrate with flight path on EHSI or weather radar, provide a dedicated display, LED or LCD, CDTI.

11. TIME OF USE: Anytime aircraft is within DABS coverage.

12. WORKLOAD IMPACT: Increases awareness of surrounding traffic resulting in some workload increases.

13. DISCUSSION: Considerable overlap exists between the ATARS advisory function and the concept of cockpit display of traffic information.

In contrast to the ATARS resolution situation, more time is available for observation and planning. In fact, functions other than collision avoidance such as approach pattern spacing could become predominant use of the advisory information.

The major drawbacks to providing the ATARS advisory information appears to be distraction and clutter of the displays and possible dissention between aircrews and air traffic controllers.

If options are to be permitted such as range, activation, suppression, position projection, A/C I.D., etc. then some control functions will be required. These will either require a dedicated panel or must be integrated with the multifunction input/output facilities.

If the system is to be integrated with the EHSI or the weather radar, this interface must be defined.

ATARS Resolution -

5. INPUT INFORMATION: Presently envisioned systems generally describe an open loop, ground command system. An onboard system could have access to information on aircraft characteristics and state for optimum evasive maneuvers. DABS would give threat data to flight director or FMS for processing ideally.

6. OUTPUT INFORMATION: Turn/don't turn (left, right). Fly down/don't fly down, fly up/don't fly up.

Output could be hard (full scale) or soft (similar to flight director) depending on situation and sophistication.

7. INPUT REQUIREMENT: None.

8. INPUT OPTIONS: None.

9. OUTPUT REQUIREMENT: Alerting Signal: Sound
Maneuver Command: Graphic
Alpha-numeric
Voice
Color, motion and blinking capabilities may be desirable.

10. OUTPUT OPTIONS: Alerting light or tone and/or voice command.
Integrate graphical command (dynamic or blinking) with EADI.
Provide a dedicated display (LED, LCD or mechanical).

Provide a modified conventional ADI.
Use existing ADI command bars.

11. TIME OF USE: Anytime aircraft is within DABS coverage.

12. WORKLOAD IMPACT:

Resolution - This function should be unobtrusive except
in avoidance maneuver situations.

13. DISCUSSION: Consideration should be given to onboard threat evaluation and resolution determination which would account for own aircraft characteristics. This would require considerably more systems integration than presently seems planned. The use of the EADI to display maneuver commands provides potential to integrate the threat evaluation aircraft characteristics and present state (altitude, airspeed, throttle setting, etc.) to provide a flight director type command. This might be accomplished through the FMS or the flight director. The EADI also provides the optimum physical placement under instrument conditions for the indications and potentially has the format flexibility to provide the function. Consideration might also be given to a HUD for similar reasons under visual conditions.

Both of the above lend themselves to dynamic symbology which may be advantageous for either the ground based or air derived system. A unique, easily interpreted attention tone or voice alert would seem highly desirable or perhaps even voicing the maneuver command would be appropriate.

The interpretation time of alphanumeric displays could preclude their use.

1. TITLE: BEACON COLLISION AVOIDANCE SYSTEM (BCAS)

2. IMPLEMENTATION SCHEDULE: Service Test - 1982
Operational - 1986

3. DESCRIPTION: The beacon collision avoidance system is an aircraft-based collision avoidance systems using on-board ATC transponders.

Current FAA plans are to have active BCAS and the DABS-ATARS systems ready for implementation at about the same time. Aircraft equipment manufacturers will begin deliveries of DABS airborne transponders with provisions for addition of BCAS capability in late 1981.

Estimates of the cost of active BCAS equipment combined with DABS transponders range from \$3,000 for general aviation aircraft to \$20,000 for airliners. Full BCAS may cost \$50,000 for an airliner installation.

Active BCAS available - 1982.

Full BCAS available - 1986.

4. OPERATING SCENARIO: The primary function of active BCAS will be to provide protection to aircraft outside ATC system coverage. In addition,

supplemental protection will be afforded aircraft operating inside ATC coverage where Automatic Traffic Advisory and Resolution Service (ATARS) is not in operation.

BCAS will normally operate automatically requiring no crew intervention unless a potential conflict is detected. In which case, indication would be provided, either through primary or auxiliary instrumentation, first intruder position and then of the appropriate evasive maneuver.

5. INPUT INFORMATION: Possible range or scale selection for some modes (Full BCAS-station keeping).

6. OUTPUT INFORMATION: Fly up/don't fly up.
Fly down/don't fly down

7. INPUT REQUIREMENT: Alpha-numeric or menu selection for some Full BCAS functions.

8. INPUT OPTIONS: Display labeled switches or menu item selection through multifunction display and keyset, FMS display and keyset or dedicated panel.

9. OUTPUT REQUIREMENT: Alerting signal: Sound
Maneuver command: Graphic
Voice
Alpha-numeric
Color, motion and blinking capabilities desirable.

10. OUTPUT OPTIONS: Alerting light or tone and/or voice command.
Integrate graphical command with EADI.
Provide a dedicated display (LED, LCD or mechanical).
Provide a modified conventional ADI.
Use existing ADI command bars.

11. TIME OF USE: Anytime aircraft is outside of ATARS coverage.

12. WORKLOAD IMPACT:

Advisory - Full BCAS advisory or station keeping may increase awareness of surrounding traffic resulting in some workload increase.

Resolution - This function should be non-obtrusive except in avoidance maneuver situations.

13. DISCUSSION: Display requirements are similar to ATARS resolution function except without left-right commands in the active BCAS version. Full BCAS would provide these, however.

Full BCAS offers a station keeping capability which could utilize a CDTI type display.

Due to the anticipated cost the future of Full BCAS is in doubt, however.

1. TITLE: NAVSTAR/GPS

2. IMPLEMENTATION SCHEDULE: Service Test - 1987
Operational - 1990

3. DESCRIPTION: GPS will provide world wide present position information to the Navigation System much like an Omega receiver or an Inertial System.

GPS will offer accurate world-wide navigation at relatively low cost to the user. Manufacturers have estimated that general aviation receivers-navigators will be available for \$4,000 to \$7,000 after 1985 and eventually cost less than \$2,000. Receivers for transport aircraft will cost \$20,000 and up. The first systems will be purchased primarily for international air carrier usage and for over water general aviation applications such as survey operations in the Gulf of Mexico. Initial airline deliveries will be for installation in new aircraft followed by retrofit as the concept becomes accepted. Collins estimates three to five thousand systems will be in use by 1990.

King Radio presently produces a VOR/DME/RNAV system (KNS-80) for \$5,500. They estimate a comparable GPS navigator will be available for \$5,000 within a decade.

4. OPERATING SCENARIO: Low cost GPS receiver-navigators will require five to eight minutes after turn on to provide the first position fix, assuming a present position input by the crew. After this initial delay the user would be provided with a continuous position, heading and distance as if he were using a VORTAC and an area navigation computer. Some systems will have internal batteries to allow them to maintain lock-on when aircraft power is removed. This will eliminate the present position input requirement and the first fix delay.

5. INPUT INFORMATION: Present position input by the crew at turn on can result in faster receiver lock-on. This will not be necessary if non-volatile memory is provided.

6. OUTPUT INFORMATION: Present position only for GPS receiver. GPS/navigation computer combination would provide standard navigation outputs.

7. INPUT REQUIREMENT: Alpha-numeric keyset.

8. INPUT OPTIONS: Flight management system keyset.
Dedicated GPS control panel.
Multifunction keyset/scratch pad display.

9. OUTPUT REQUIREMENT: Perhaps alpha-numeric display for system monitoring. Output would normally only be used by the navigation system. General aviation and retrofit systems may combine GPS navigation receiver and navigation computer.

10 OUTPUT OPTIONS: Flight management system display, multifunction display, dedicated display, flight instruments.

11. TIME OF USE: GPS may be used throughout the flight. No effect on

information currently displayed will result from its use.

12. WORKLOAD IMPACT: GPS could significantly reduce nav-aid selection effort, otherwise there is no significant impact.

13. DISCUSSION: The global positioning system will provide world wide position fixing independent of ground stations. The system frequency is fixed, eliminating channel selection. Present position input is only required to reduce lock-on time. Non-volatile memory or internal battery power can eliminate this.

In large aircraft systems the GPS receiver-processor would supply present position data to the navigation or flight management computers which would, in turn, drive the flight instruments. GPS receiver control could be through the FMS or through a dedicated control head.

Smaller aircraft will have combined GPS-navigation systems which will combine the receiver, navigation computer, keypad, control and digital display in a single box, similar to currently available general aviation Omega and VOR navigators.

1. TITLE: VOICE OUTPUT

2. START OF AIRLINE USE: Service Test - Currently
Operational - 1980 (DC-9-80)

Comments:

Voice annunciation has been used for several years in the Ground Proximity Warning System (GPWS) and is being offered as an optional method of caution-warning annunciation on the DC 9-80 by McDonnell-Douglas. Voice output may be accomplished using either synthesized or digitized speech. Several semi-conductor manufacturers are developing specialized integrated circuits for speech output.

3. COCKPIT INFORMATION: Voice output provision information output channel for such data as caution- warning, altitude, airspeed, position, checklists, etc.

4. OPERATING CONTROLS:
On/Off
Volume

5. DATA ENTRY REQUIREMENTS:
None

6. Operating Scenario: Voice output may be used to provide aural indications of caution-advisory- warning information to reduce ambiguity of the present sound annunciation system. In addition, the technique could be used for information outputs (such as latitude on approach) to reduce instrument scan requirements during high risk work load periods. Consideration must be given

to possible conflicts with ATC or other voice communications. Experience has indicated that operation is enhanced by preceding the voice output with a standardized alerting tone.

1. TITLE: SPEECH RECOGNITION

2. IMPLEMENTATION SCHEDULE: Service Test - 1985
Operational - 1990

3. DESCRIPTION: Speech recognition has been shown to be a practical and efficient means of data entry and control for many industrial applications. Considerable research and development work has been funded by ARPA and the military since the early 70's. Recent advances in microcomputers and digital signal processing techniques are making possible light-weight compact systems which will be suitable for aircraft installation.

4. OPERATING SCENARIO: Speech recognition allows the user to operate equipment by voice control. Potential applications include radio channel selection, navigation data entry, checklist item acknowledgement and stored data retrieval.

A radio channel might be selected by simply pressing the LISTEN switch, perhaps on the control column, and saying, "RADIO ONE-TWO-THREE-POINT-FIVE." The words "RADIO 123.5" might then appear on a visual display or be spoken back by synthesized speech for verification. Saying "Yes" and releasing the LISTEN switch would cause the radio channel to be selected. Saying "No" at any time in the sequence would delete the previous entry and allow for correction.

1. TITLE: COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)

2. IMPLEMENTATION SCHEDULE: Service Test - 1990
Operational - ?

3. DESCRIPTION: The cockpit display of traffic information is a scheme to put information on surrounding aircraft into the cockpit and return some of the responsibility for maintaining separation to the cockpit. There is also the possibility of pilots taking on some of the responsibility for metering and spacing.

A great deal of investigation will be necessary to determine the merits and methods of implementing CDTI. Consideration must be given to the impact of CDTI on pilot work load, communication requirements and traffic flow. To what extent will the advantage of possible detection of ATC errors be offset by problems caused by unnecessary evasive actions or questioning of ATC instructions? What criteria should be used to determine the display scale and to select the aircraft presented?

4. OPERATING SCENARIO: CDTI would primarily be used during climbout and terminal area operations to provide the position of surrounding air traffic.

This could allow the pilot to become involved in traffic flow decisions, thereby distributing the work load of Air Traffic Control. Its usage could be limited to situation observation with pilot discretion only being allowed during emergency evasive maneuvers.

5. INPUT INFORMATION: Service request
Range or scale desired
Momentary or continuous display
Other aircraft designation to onboard computer
for merging or schedule keeping.
6. OUTPUT INFORMATION: Relative position of proximate aircraft, range or scale of displayed information, I.D., altitude, speed, etc. of surrounding aircraft (at least on request).
7. INPUT REQUIREMENT: Alpha-numeric and/or choice select probably using DABS as the information source. Graphical (cursor), pointer (touch panel) or alpha-numeric aircraft designation capability.
8. INPUT OPTIONS: Keypad (FMS, ATARS, DABS or portable), multifunction (display labeled) or dedicated switches around EHSI, weather radar or FMS display. Touchpanel or trackball controlled cursor may be useful to designate specific aircraft.
9. OUTPUT REQUIREMENT: Graphics display, alpha-numeric display for input scratchpad or menu and possibly for information request.
10. OUTPUT OPTIONS: Integrate on EHSI, use weather radar or provide dedicated display, possibly annotate with alpha-numerics. FMS display or multifunction display for system control scratchpad, requested data, etc.
11. TIME OF USE: At crew option. Probably primarily in the terminal area.
12. WORKLOAD IMPACT: CDTI would increase the flight crew's awareness of surrounding traffic, could reduce plane spotting effort and could result in more crew responsibilities.
13. DISCUSSION: Although usually thought of as a DABS data link function CDTI could also be derived from full BCAS or even a composite of multiple sources.

In addition to traffic watching, CDTI could assist in merging in the terminal area, metering and spacing, and station keeping (perhaps on trans-Atlantic flights).

Potentially, CDTI could be used to designate an aircraft to the onboard computer. After such a "lock on" a fast/slow indication could be provided to maintain precise separation.

Momentary presentation of CDTI on request could be desirable for VFR plane spotting without significantly increasing display clutter or distraction.

Only aircraft in a predefined altitude band would normally be viewed.

Range selection as a function of aircraft speed and direction should be considered.

1. TITLE: COCKPIT ALERTING AND WARNING SYSTEM (CAWS)
2. IMPLEMENTATION SCHEDULE: Evolutionary
3. DESCRIPTION: The proliferation of techniques for this function in the cockpit has generated interest in the FAA in a system's approach to provide some standardization and a study is now in progress to this end. This subject is included here because it is a needed input into cockpit integration schemes.

The introduction of the video display into the cockpit provides much flexibility in the presentation of CAWS information. Voice output can further reduce the ambiguity of the multitude of horns, clackers, warblers and tones currently used to announce an even greater number of events. Much work is still required to specify appropriate methods and to prioritize messages to achieve the best results. Boeing, McDonnell- Douglas and Lockheed are engaged in a study effort to standardize CAWS techniques.
4. OPERATING SCENARIO: CAWS generates aural and visual indications of malfunctions or potentially unsafe conditions. During normal situations the system is unobtrusive. When a failure occurs, a tone might sound followed by a flashing indication on a CRT of the specific problem. There may, in addition, be a synthetic or digitized voice annunciation of the event. The crew would probably acknowledge the annunciation by a keyboard or display labeled switch input which would stop the flashing; however, the readout would remain until the fault was cleared. An outstanding feature anticipated in future CAWS implementations will be the suppression of inappropriate annunciations during critical flight phases such as takeoff or landing. Cautions and warnings would be prioritized to prevent distractions which could create more serious hazards than those annunciated.
5. INPUT INFORMATION: Flight phase should be automatically obtained from FMS or sensor data. Acknowledgement may be required for some functions.
6. OUTPUT INFORMATION: Caution, advisory and warning messages, prioritized.
7. INPUT REQUIREMENT: Manual acknowledgement of some messages.
8. INPUT OPTIONS: Display labeled switch, touchpanel, keyset.
9. OUTPUT REQUIREMENT: Alpha-numeric display, alerting signal, color desirable to indicate urgency.
10. OUTPUT OPTIONS: Dedicated display desirable. Multifunction display possible if prioritized for CAWS. Alerting tone and/or voice output should be considered. Critical warnings should be adjacent to or integrated with primary flight display.
11. TIME OF USE: CAWS will be used throughout the flight, but will have

dynamic prioritization to limit the impact of alerts as is appropriate to the flight segment.

12. WORKLOAD IMPACT: The objective of CAWS is to optimize critical information transfer while minimizing workload impact. CAWS should be unobtrusive until needed. The visual and aural alerts should then be sufficient to attract the crews attention to the situation.

13. DISCUSSION: Considerable work is being done to define CAWS functions, priorities and techniques.

Conceivably a multifunction display could be used for CAWS output prioritized as necessary.

The desire for minimum response time on the part of both system and crew may preclude shared hardware, however.

1. TITLE: - ARINC COMMUNICATIONS ADDRESSING &
REPORTING SYSTEM (ACARS)

2. IMPLEMENTATION SCHEDULE: Service Test - Approx. 1976
Operational - 1978

3. DESCRIPTION: ACARS is a company communication data link operating through conventional VHF radios to a ground network operated by ARINC. Much of the company information flow can be handled automatically by ACARS. ACARS is rapidly being adopted by airlines because of its efficiency, decreasing ARINC charges for time on the network, increased automation of company record keeping, and decreased workload in the cockpit.

This is two-way data link operating through VHF comm transceiver to ARINC ground network. Minimum form: A/G transmission of 000I times; fuel aboard, out and in times; A/G/A voice signaling. Cockpit control unit provides entry of: Departure/arrival times, ETA, and ground telephone numbers for voice communications. It contains scratch pad for display of above, and radio frequency, stored 000I, flight number and GMT when called up. Systems options are: Cockpit hard copy printer, and an Optional Auxiliary Terminal (OAT) for non-cockpit use providing G/A data comm.

4. OPERATING SCENARIO: There are two operating modes: "Demand" for low density environments, and "polled" for high density environments. On turn-on, "Demand" is automatic. The ground system commands "Polled" when necessary.

Before departure, pilot inserts A/C ident, departure point, destination, and fuel aboard. 000I transmissions are automatic.

In flight: Pilot receives phone calls as annunciated, and inserts phone number to call ground party. Receives hard copy print-out of weather, and of flight plan changes.

5. INPUT INFORMATION: Airline office communications, information requests, progress reports.
6. OUTPUT INFORMATION: Airline office communications, weather information, flight plans.
7. INPUT REQUIREMENTS: Alpha-numeric keyset.
8. INPUT OPTION: ACARS dedicated keyset.
Multifunction keyset.
FMS Keyset.
9. OUTPUT REQUIREMENTS: Alpha-numeric printer or display.
10. OUTPUT OPTIONS: Dedicated or multifunction printer, multifunction display, FMS display, weather radar display.
11. TIME OF USE: ACARS will be used throughout the flight.
12. WORKLOAD IMPACT: Reduces overall workload by providing improved company communications, printed text output and automatic flight accounting.
13. DISCUSSION: The ACARS keyset and printer provide alpha-numeric input/output capability which could be integrated with other systems. This might be attractive when retrofitting DABS data link to older aircraft.

In future aircraft, integration of alpha-numeric keysets, displays and printers would allow multiple usage. This would improve layouts, reduce costs, and provide standard access for input/output for communications, navigation, maintenance and record keeping.

1. TITLE: DISPLAY OF WEATHER INFORMATION - CDWI
2. IMPLEMENTATION SCHEDULE: Service Test - 1990
Operational - 1995
3. DESCRIPTION: Cockpit display of weather information covers the subject of transferring weather information to the flight crew.

Operational usage depends on the availability of sufficiently well defined, wide area weather data. The hardware capability will be available when the DABS data link becomes operational in 1984.
4. OPERATING SCENARIO: Select CDWI option, enter desired location and perhaps time, observe display.
5. INPUT INFORMATION: Service request.
Range or scale desired.
Momentary or conditions display.
Location of desired weather if not local.
Time, if forecast is desired.

6. OUTPUT INFORMATION: Relative position, extent and intensity of storm cells, turbulence and other weather conditions.

7. INPUT REQUIREMENTS: Alpha-numeric and/or choice select, probably using DABS as the information source.

8. INPUT OPTIONS: Keypad (FMS, ATARS, DABS or portable), multifunction (display labeled) or dedicated switches around EHSI, weather radar or FMS display.

9. OUTPUT REQUIREMENTS: Graphic or pseudo-graphic weather display Alpha-numeric display for input scratch pad or menu color graphics desirable to indicate intensity.

10. OUTPUT OPTIONS: Integrate local weather on EHSI, use weather radar or multifunction display, possibly use FMS display for alpha-numeric pseudo-graphic display.

11. TIME OF USE: CDWI may be used throughout the flight at the flight crew's option providing facilities are available.

12. WORKLOAD IMPACT: CDWI should reduce workload by providing clear, more specific data on the position, extent and intensity of weather conditions.

13. DISCUSSION: Usually suggested as a potential DABS function. Could provide a weather radar like image with the advantage of seeing the other side of intense weather. The service facilities are far in the future at best.

If presented as requested and integrated with EHSI data, CDWI could provide a convenient means of situation analysis and route deviation planning.

If a trackball controlled cursor were added to the EHSI, RNAV inputs to go around a storm cell could be input to the navigation system directly.

Some work has been done toward presenting similar weather data on an alpha-numeric CRT display using a pattern of digits of define storm location, shape and intensity.

1. TITLE: CHECKLIST DISPLAY

2. IMPLEMENTATION SCHEDULE: Currently available.

3. DESCRIPTION: Checklists ensure that aircraft systems are operating normally and are properly set for particular phases of aircraft operation.

4. OPERATING SCENARIO: Prior to significant operations checklists must be used to assure proper procedure.

5. INPUT INFORMATION: Selection of checklist, accomplished, checked and skip-save inputs.

6. OUTPUT INFORMATION: Checklists of complex tasks.
7. INPUT REQUIREMENTS: Alpha-numeric or menu selections checked/skip input.
8. INPUT OPTIONS: Keyset (FMS, ACARS, Portable)
 Display labeled switches for menu select or check off
 Touch panel
 Paging and check off through dedicated panel
 Voice
9. OUTPUT REQUIREMENTS: Text display (multiple lines desirable), skipped items should remain on screen or go to end of list. Color may be desirable to highlight the line being checked if several items are displayed simultaneously.
10. OUTPUT OPTIONS: Multifunction display, FMS display.
 Weather radar display, LCD display
 Voice output could be a useful option.
11. TIME OF USE: The checklist display capability similarly to present checklists before critical flight activities.
12. WORKLOAD IMPACT: Checklist display should slightly reduce workload by providing a more convenient way to accomplish the required tasks.
13. DISCUSSION: Checklists require large amounts of memory and an effective means of indexing and selection. This should present no problem in future systems.

A means of place keeping and a checkoff tally should be provided.

Some means of re-entering a checked off item would be desirable.

Some checklist items should be considered as automation candidates. Tell a monitoring system the flight phase and receive an indication of out of compliance system states. Consider automating control functions based on the flight phase input.

A voiced output option of the checklist might be a practical consideration, particularly in one or two man cockpits.

Checklist item acknowledgement appears somewhat cumbersome. Voice recognition may eventually provide an alternative to manually switches.

Checklist display would be required for a relatively small portion of flight time, usually prior to high intensity work periods.

1. TITLE: WINDSHEAR WARNING
2. IMPLEMENTATION SCHEDULE: Currently available.
3. DESCRIPTION: Because of the hazards involved, a great deal of work has

been done on detecting and alerting aircraft to the presence of windshear. Two approaches are being pursued. Ground derived systems using multiple anemometers and airborne systems using inertial and other techniques have been investigated.

Although rudimentary windshear warning devices are now available, some research is in progress both on airborne and ground based windshear warning systems. The airborne system can only respond to its environment. Ground based systems can be anticipatory.

4 OPERATING SCENARIO: Either type system would provide alarms and commands to the crew or the autopilot. The ground based system could calculate and present a desired ground speed for safe approach.

5. INPUT INFORMATION: Windshear detection activation
Airspeed, groundspeed, radar altitude
6. OUTPUT INFORMATION: Windshear warning, maneuver and power commands,
required ground speed for conditions, ground speed/airspeed
7. INPUT REQUIREMENTS: Alpha-numeric or analog.
8. INPUT OPTIONS: FMS keyset, multifunction keyset, knob.
9. OUTPUT REQUIREMENTS: Graphics or electromechanical analog indication.
10. OUTPUT OPTIONS: Integrate with EHSI.
Provide dedicated airspeed/ground speed indicator.
Tone or voice alert and/or command.
11. TIME OF USE: Windshear warning will be available during takeoff and landing phases.
12. WORKLOAD IMPACT: Workload will increase if manual windshear management is utilized because of the need to calculate and maintain higher approach ground speeds.
13. DISCUSSION: Windshear warning systems may be either ground or aircraft based. The ground based systems depend on a number of sensors around an airport to detect extreme wind variations.

The onboard system depends on detection of variation in airspeed and the difference between airspeed and ground speed.

1. TITLE: FOUR DIMENSIONAL AREA NAVIGATION (4D RNAV)
2. IMPLEMENTATION SCHEDULE: Service Test - 1984
Operational - 1988
3. DESCRIPTION: Two-D, 3-D, and 4-D navigation are all of interest. Area navigation systems today provide navigation and guidance to fly great circle courses and vertical flight pattern automatically. The technology of 4-D

navigation, which adds time, has been demonstrated.

Four dimensional area navigation will be supportive of enroute metering. Similarly, 4D RNAV requires enroute metering to be justifiable. There is little advantage of arriving in the destination vicinity on schedule to be placed in a holding pattern. The two concepts are mutually supportive and are separately impractical. Combined, they offer the potential of reducing aircraft fuel and operating costs, increasing airport efficiency, providing a safer flight environment and relieving the peak workloads of both pilots and air traffic controllers. The fulfillment of this promise will have to await the installation of more powerful ATC computer systems in the late 1980's.

4. OPERATING SCENARIO: The waypoint and schedule of a flight would be entered prior to take-off and the system would adhere to it throughout the flight. Enroute deviations would be entered as necessary and their schedule effects defined. The system might allow conflict resolution during the planning stage though the use of an enroute metering clearing house. In flight the system would normally operate through the Flight Management System to minimize fuel within the constraints of the schedule. Monitoring and manual flight could be facilitated by providing a "time box" indication on the EHSI to show the optimum present position.

5. INPUT INFORMATION: Flight plan, deviations, descent profiles, time at metering points.

6. OUTPUT INFORMATION: Position, course, heading, deviations, times, distance to go, scheduled position versus present position, faster/slower or throttle commands. Possible prestored and/or uplinked overlays of obstacles, weather, approach paths.

7. INPUT REQUIREMENTS: Alpha-numeric data entry. Possible trackball or joystick controlled cursor for deviation entry directly on EHSI.

8. INPUT OPTIONS: Keyset (FMS or multifunction)
ACARS
DABS
Magnetic Card
Trackball or Joystick

9. OUTPUT REQUIREMENTS: Alpha-numeric display
Graphics display

10. OUTPUT OPTIONS: FMS or multifunction display for flight plan
entry or checking.
EHSI for position and progress
Engine instruments for throttle commands.

11. TIME OF USE: RNAV will be used throughout flight.

12. WORKLOAD IMPACT: RNAV will reduce overall workload, but will require some increase prior to flight and when flight plan changes are necessary or when navigation data requires update. Generally the effect will be to spread and reduce previous workloads.

13. DISCUSSION: The EHSI provides the primary output for navigation. The major consideration is determining the format, amount and type of data to be presented to provide adequate information for safe accurate guidance, monitoring and planning without degrading crew efficiency and response capability because of excessive display clutter.

In addition, the navigation system requires some form of input and scratch pad and control functions. Alpha-numeric displays (digital or CRT) and keysets currently fulfill these requirements. At least one general aviation system uses a magnetic card for optionally entering pre-defined flight plans.

Future systems may rely on data link for flight plan input.

In route deviations and terminal navigation under automatic control could utilize RNAV waypoint input directly through the EHSI by means of a cursor and trackball.

Four-D RNAV requires schedule and speed command provisions and perhaps throttle commands.

1. TITLE: PROFILE DESCENT

2. IMPLEMENTATION SCHEDULE: Technology currently available.

3. DESCRIPTION: The objective of profile descent is to keep an aircraft at high altitude as long as possible to conserve fuel, then descend in a throttled-back configuration so as to arrive at a metering fix at a specified time, altitude and speed.

Profile descents have been under study for some time as a means of fuel conservation. The concept is now receiving attention as a means of organizing terminal area traffic flow. This requires the addition of time to the three spatial dimensions required to define a descent path. The additional computation is well within the capabilities of available flight management systems. The major problems appear to lie with ATC in being able to determine the ideal arrival times to properly merge aircraft during saturation periods.

4. OPERATING SCENARIO: Desired descent profile and metering point arrival time would be negotiated between the flight crew and ATC with the aid of on-board and ground computations. The resulting descent profile information would be entered into the flight management or navigation computer which would then provide pitch and throttle commands to maintain the descent path and schedule.

5. INPUT INFORMATION: Desired descent schedule (e.g. min cost, min fuel) Metering fix location and desired arrival time.

6. OUTPUT INFORMATION: Optimum beginning of descent point, pitch and thrust commands.

7. INPUT REQUIREMENTS: Alpha-numeric data, possibly menu selections, possibly, cursor designation.
8. INPUT OPTIONS: Flight management, area navigation or multifunction keyset, possibly trackball controlled cursor.
9. OUTPUT REQUIREMENTS: Alpha-numeric and possibly graphic scratch pad for input data. Alpha-numeric and graphic display of system generated maneuver commands.
10. OUTPUT OPTIONS: Flight management, area navigation or multifunction display for input scratch pad, EADI, EHSI for maneuver commands.
11. TIME OF USE: Prior to and during descent.
12. WORKLOAD IMPACT: Profile descents will increase the computational and monitoring workload unless some automation is provided. Some workload reduction may result if terminal area congestion is relieved by using it.
13. DISCUSSIONS: Profile descents will become an integral part of flight management systems and will use the input/output facilities provided for data entry. Maneuver commands will use the flight instrument displays to achieve the desired descent path and to provide monitoring of auto-descent. Consideration should be given to a momentary display of the vertical profile to assure proper input.

1. TITLE: FLIGHT MANAGEMENT SYSTEM

2. IMPLEMENTATION SCHEDULE: Currently available.

3. DESCRIPTION: The FMS is an integrating system designed to bring together operations functions in a convenient form to reduce crew workload. The system provides aircraft performance data, fuel management, navigation and guidance, and throttle management in a cohesive manner to automatically fly a desired flight plan based on efficient profiles.

Flight management systems are becoming the focal point of cockpit integration. In order to accomplish the functions of navigation, guidance and energy management, the system must have access to a vast store of aircraft status data as well as geographical and nav-aid data. The system requires an alpha-numeric keyset and scratch pad display. In addition, it has access to the flight instruments for information output. In future aircraft this provides graphics capability with considerable flexibility. Since neither the keyset nor the scratch pad are heavily used by the navigation functions, they are likely candidates for communications channel selection. The alpha-numeric input/output capability is also attractive for both DABS and ACARS data link functions. This provides tremendous potential for extensive communications between air and ground computers. Systems are presently being offered with magnetic card flight plan entry.

4. OPERATING SCENARIO: Flight plans would be entered or selected prior to flight, deviations and updates would be entered as required during flight.

Keyset and display may be used for other functions as practical.

5. INPUT INFO: Flight plans, deviations, operating modes, aircraft status, possibly data link communications. Message, systems control inputs, check list selection and item acknowledgement, communication channel selection.

6. OUTPUT INFO: Guidance and thrust commands, fuel management information, aircraft state, present position, possibly data link communications messages, check list display.

7. INPUT REQUIREMENTS: Alpha-numeric data, text possibly graphic input with cursor.

8. INPUT OPTIONS: Keyset either dedicated or multipurpose, display labeled switches, dedicated switches, possibly trackball controlled cursor.

9. OUTPUT REQUIREMENTS: Alpha-numeric display, analog flight command displays.

10. OUTPUT OPTIONS: Dedicated or multipurpose alpha-numeric display (CRT, LCD, LED, etc), EADI, EHSDI, ADI, HSI raster scan weather radar.

11. TIME OF USE: Throughout the flight.

12. WORKLOAD IMPACT: Preflight workload will sharply increase for complex routes unless magnetic card, tape or data link entry is used. The inflight workload is considerably reduced.

13. DISCUSSION: The exploitation of the combined concepts of a flight management system and an integrated input/output system provides the potential for greatly increasing cockpit efficiency. The flight management system has access to aircraft state, flight plans, navigation data and time schedule information. If data link interface is provided, direct access to ATC and company computer information may be available on request or with automatic update. Stored maps, checklists, approach templates and flight plans can be quickly retrieved. Communications channels may be automatically selected from stored or uplinked data or manually selected through the keyset. Flight plan deviations around storm cells could be input by cursor selection through the EHSDI.

This vast amount of information must be carefully managed, filtered and presented in a comprehensible form in order to be usable. Given human limitations for information transfer, the flexibility of electronic input/output facilities provide the ideal means to format data into the most advantageous configuration within the confines of the cockpit space. A great deal of work will be required to define which information will be best input or output, at what time, using which device, and in what form (i.e. graphical, alpha-numeric, speech, etc.).

APPENDIX D

AIRCRAFT TIME DIVISION MULTIPLEX DATA BUSES

INTRODUCTION

Integration of electronic systems requires that interconnection paths be established between sources of information and users of information. There are four categories of these interconnections: single source/single user, single source/multiple users, multiple sources/single user, and multiple sources/multiple users. Prior to the entry of digital equipment and digital data buses into aircraft, all interconnections were made with point-to-point wiring to form a dedicated path for each individual signal. As aircraft complexity increased, wiring became an increasing problem from a weight, increased cost of fabrication, installation, and maintenance standpoint. The perfect aircraft cable connector has yet to be invented and increased interconnection requirements increased wiring integrity problems.

The above situation has been changed by the rapid adoption of digital equipment and data buses. Instead of hard wiring all information paths, information is collected, coded into digital words, and routed serially over data buses to users where the information is decoded, all under software control.

Multiplex digital data buses will assume an increasingly greater role as the means for integrating aircraft systems. Time division multiplexing is in use today both commercially and by the military but other multiplexing schemes, such as frequency division, may be used in the future. Time division multiplexing is the transmission of information from multiple signal sources through one communication system by staggering the time that information from each signal source is transmitted on the bus. These time slices of signals form a composite pulse train of binary digits flowing on the bus. Individual signals are recognized, decoded and used at their destination.

Commercial and military data buses have developed along different lines. ARINC standard buses, as defined in ARINC Specifications 429 and 453, are used in commercial applications. Military standard buses are defined by MIL-STD-1553. Future data bus concepts are likely to be influenced by developments in distributed computer processing and fiber optics.

ARINC DATA BUSES

ARINC data buses are transmitter controlled and are based on a "broadcast" system philosophy. Any equipment having data to transmit does so by broadcasting the data in pulse coded serial digital form over a single twisted and shielded pair of wires. All receivers having need of these data are connected to this bus. All ARINC data buses use

32-bit words of which eight bits are reserved for standardized coded identification of the data contained in each word. These identification labels are decoded in the receivers for information selection. Each bus transfers data in one direction only - from transmitter to receiver(s).

ARINC 429 buses are specified to operate at either of two speeds. The low-speed bus operates at approximately a 12.5 kilobits per second rate which is sufficient for most current applications. A 100 kilobits per second 429 bus is used for applications requiring a higher data refresh rate than can be accommodated by the low speed bus - electronic flight instruments for example. Return-to-zero (RZ) bipolar coding is used which is a tri-level state modulation consisting of "Hi", "Null", and "Lo" states. Clocking is inherent in the data transmission with the bit interval identified by initiation of a "Hi" or "Lo" state from a previous "Null" state. Synchronization is accomplished by gaps between word transmission periods with the beginning of the first transmitted bit following the gap indicating the beginning of a new word. No error correction means are incorporated. Error detection is by parity checks and, wherever required, by reasonableness checks at the receivers.

The ARINC 453 very high speed data bus was developed subsequent to the 429 bus because of a need for a higher data rate. This system was brought about specifically by digital color weather radar requirements.

ARINC 453 buses are specified to operate at a one megabit-per-second bit rate. Manchester II bi-phase code is used with a logic one transmitted as a positive pulse followed by a negative pulse and a logic zero transmitted as a negative pulse followed by a positive pulse. The transition through zero occurs at the midpoint of a clock cycle. Synchronization is accomplished by preceding a 32-bit word with a 3-bit sync pattern and a pad bit. The sync pattern is an invalid Manchester code that consists of a positive pulse extending over one and one-half clock periods followed by a negative pulse over the next one and one-half clock periods. Transition through zero occurs at the midpoint of the second clock cycle. The sync pattern is followed by a logic one pad bit and a 32-bit word without gaps. No data error correction provisions are incorporated and error detection is accomplished in the same manner as ARINC Specification 429. ARINC 453 permits multiple transmitters on a single bus in contrast to ARINC 429. Selection of this option requires provisions to insure that only one transmitter is active at any one time.

MIL-STD-1553B DATA BUSES

MIL-STD-1553 data buses are based on a command/response philosophy, i.e. all bus traffic is initiated by a bus controller which commands responses in accordance with the bus controller's program, from terminals connected to the bus. Bus traffic is bi-directional and messages travel in either direction but not at the same time (half-duplex). Terminals, commonly referred to as remote terminals, are used to interface subsystems with a data bus. They may be stand-alone units or an integral part of subsystems. All terminals connected to a particular bus have unique 5-bit addresses which could permit up to 32 terminals on a single bus. Messages may be exchanged between a bus controller and any terminal on the bus between a terminal and the bus

controller, or between any terminal and any other terminal. All exchanges are conducted, however, only by commands from the bus controller.

MIL-STD-1553 allows a remote terminal to assume the bus control function when it is configured to do so. This is known as distributed control. Bus control can therefore be handed off from unit to unit during a bus cycle but only one is in command of the bus at any one time. A third mode of bus operation is included in the standard known as the "broadcast" mode. This allows a single source to broadcast information to multiple terminals in a single message.

The 1553 system operates at 1 megabit-per-second bit rate over a twisted pair and shielded wire-bus. The word format is 20-bits, of which three are reserved for sync and one for parity. Three word formats are used consisting of a Command Word which is only transmitted by a bus controller, a Data Word which may be transmitted by any unit on a bus, and a Status Word which is only transmitted by remote terminals to keep the bus controller informed on terminal status. The first three bit times of any word transmitted is occupied by the sync which is invalid Manchester coding. Command and status words have a positive waveform for the first one and one-half bit period and a negative waveform for the next one and one-half bit period with the transition through zero occurring at the mid point of the second bit period. Data word sync is the inverse of the command and status word syncs.

Error detection and correction features are provided for in MIL-STD-1553. Messages are validated by receiving terminals and the bus controller is notified by the terminals as to the success of a data transfer. Other features enable a controller to manage the bus operation by determining problem sources and actions required to resolve the problems.

The use of redundant buses for reliability reasons is an option of MIL-STD-1553. Experience has shown that dual buses are ample for avionics systems and that flight controls should have triple or higher redundancy for safety reasons. The military services are committed to MIL-STD-1553B and all aircraft requirements for digital data transmission will use this standard.

ARINC AND MILITARY DATA BUS COMMENTARY

The commercial ARINC data bus is best suited to applications involving a single source that must transmit information to one or more receivers. The ARINC approach permits separation of functions. This uni-directional bus system is low in cost and requires only simple transmitters and receivers. The system is "open-loop" in that a transmitting source broadcasts its messages repetitively but receives no intelligence on the success or failure to transfer data. Any error detection capability must reside in the receivers. Parity checks and data smoothing to remove "wild" data points are techniques available for suppressing erroneous data.

Experience with ARINC data buses has been good. Trends in avionics bring into question, however, their survival in the future in present

form. Higher levels of integration with requirements for two-way close-loop communications between multiple sources and users will create a need to reassess their assets and liabilities for future applications. Each ARINC bus provides dedicated data paths for dedicated purposes. If two-way communication is required, two dedicated data buses are required. Requirements for multiple sources transmitting data to single or multiple receivers expands requirements for buses to be installed. This increases aircraft wiring complexity, cost, and weight. In these circumstances, the simplicity of the bus itself will have to be balanced against increased wiring complexity in the aircraft.

ARINC data buses provide a simple and economical means for digital transmissions in aircraft. These benefits are obtained at the expense of a lack of flexibility that is offered by multi-access bi-directional buses. Retrofit of new equipment in aircraft would require the addition of new buses, an expensive proposition. Multi-access bus equipped aircraft would require localized modifications to connect new equipment to the bus system and software changes to incorporate the equipment into the network.

The MIL-STD-1553 bus provides a great deal of flexibility in its use but at the expense of much increased complexity and cost as compared to the ARINC approach. The bus structure can be likened to a digital transmission highway where transmitters and receivers of data can be connected to communicate over a common time-division multiplexed data path. The system is closed loop for data transfer confirmation and for trouble isolation and correction.

Since a command/response system requires that a bus controller initiate and sanction all bus traffic, provisions must be made for a second controller to take over the job of the primary controller to prevent loss of a complete bus system should the primary controller fail. Means must be included in system design to determine when and how the switchover to a backup controller is done. All communications on a bus require, as a minimum, a command word from the controller and a status word from the terminal involved in the communications except when a broadcast message is transmitted. Terminals do not reply with status words in this situation. In the case of a terminal to terminal transfer, two command words must be issued by the controller to notify each terminal what it is to do and two status words are required, one from each of the terminals involved to account for their status. Command words and status words are part of the software overhead required by the MIL-STD-1553 format and consume time on the data bus at the expense of data throughput. The overhead required to operate a bus system is important in real-time applications because of data updating requirements. It is for this reason that buses are more efficient when controllers are located in central processors. Information that is already in the central processor can be acquired by the bus controller without use of data bus time. The processing capability of the central processor can be used to organize data for efficient transmission. Since each message, regardless of data content requires the transmission of at least one command word and one status word, higher efficiency is obtained when data can be organized for a maximum number of data words per message.

MIL-STD-1553 is a well-proven bus system which is in use on a number of military vehicles and in laboratory integration facilities. Few buses are required and the "party-line" concept considerably reduces aircraft wiring complexity and wire weight. MIL-STD-1553 is inefficient, however, for applications involving a single source and multiple users of data. If the command/response protocol is used then a controller transaction with the source and with each of the users is required which loads the bus with overhead to accomplish in a real-time system. If a broadcast mode is used, there is no automatic check that the information was successfully transferred. Provisions are made, however, in the standard, for subsequent interrogation of terminals individually to verify their acceptance of a broadcast message. Repetitive broadcasts could be used but this also consumes valuable time on the bus.

FUTURE DATA BUSES

Digital data transmission standards of the future will be determined by the manner in which electronic design/integration trends develop and the resulting demands placed on data buses. The availability of low-cost microprocessors and microcomputers in recent years has led to their rapid inclusion in aircraft hardware. These developments naturally lead to thoughts of data processing centers, with modest software requirements that are distributed throughout the aircraft. Further, these local computers are envisioned to be tied together by some type of data bus structure to accommodate information transfer and system management requirements. This approach is commonly known as "distributed processing", "distributed architecture" or "distributed intelligence".

Distributed processing is advantageous for real-time applications. Since tasks can be performed asynchronously and in parallel as contrasted with the serial operation of centralized systems. Distributed systems do, however, increase data bus requirements for transferring data and supervision of the system. These additional message requirements can be minimized somewhat by care to assign to the same processor tasks that frequently interact.

The anticipated trend toward more distributed processing plus other factors make it highly probable that future airborne requirements will exceed the capabilities of the present 1 megabit rate serial data bus systems. Since spare computing capability can be obtained at low cost, the ability to reconfigure systems with little or no loss of performance in case of failures may create the need for high-speed computer-to-computer interchanges over a data bus. Voice recognition and synthesis technologies will generate requirements for transmission of digitized voice over data buses. The need to transmit digitized video over data buses may increase. These factors lead one to believe that higher speed buses will be required in the future. The present transmission medium, a pair of twisted and shielded wires, will not be useable because of bandpass limitations and will be replaced by some other medium - probably fiber optic.

Requirements for higher data rates than presently available from half-duplex serial digital standard data buses can be achieved by a

changeover from twisted pair and shielded wire buses to fiber optic buses and by increasing the data bus system rate. Centralized controllers are excellent for maintaining a reliable communications system but do have a few drawbacks some of which have already been mentioned. Others are as follows: Centralized controllers require complex software with the associated problems of cost to develop, checkout, maintain and modify. Bus time is required to transact business with each terminal on a bus in accordance with the controller's program without regard to whether or not the transaction is useful or necessary at the moment. If data has not changed significantly since the last transaction, then valuable bus time has been consumed for no useful purpose. Also there are problems of delay in transmitting randomly-occurring high priority messages or other time limited aperiodic messages. The terminal with such a message must wait until contacted by the controller and a message path is established to the receiving terminal. For these and other reasons, a great deal of interest has been generated in "Contention" concepts of bus control. These concepts eliminate centralized bus control and allow terminals to contend for use of the bus.

There are many contention concepts which could be implemented. All involve listen-while-talk features, i.e., terminals continuously monitor the bus including the time of its own transmission. One example of contention bus control is discussed in the following paragraphs.

When a contention bus terminal has a message to send, it waits to detect a quiet bus. Upon detection, a random delay time out which is related to the message priority is started. The message is transmitted at the end of the timing cycle if the bus has continued in a quiet state. The transmitting terminal continues to monitor the bus to verify that its transmitter is the only one on the bus. If a data collision is detected, i.e. two or more transmitters on the bus, the terminal ceases communications. The terminal then reschedules its message by starting another bus acquisition cycle. The randomness in the delay cycles for bus acquisition enables terminals to gain access to the bus.

Communication integrity could be insured by handshakes between terminals to verify the success of data transfer and that terminals are functioning normally. A "broadcast" mode might also be selected since the higher data rate capability of fiber optics buses as compared to current twisted wire buses could tolerate repetitive broadcast of messages to smooth data.

The two concepts of bus control, command/response and contention that were previously discussed, will be competing in the future for control of high speed half duplex serial digital data buses. How integration schemes evolve and how the two competing approaches fit the future from a reliability and cost standpoint will determine the outcome. The large investment, good experience, and commitment to standardization of the military on command/response bus systems presents a formidable hurdle to competing schemes. Similarly, the airlines have a large investment, good experience, and commitment to standard ARINC data buses. Changes in concepts will come about, however, by evolution as requirements shift with time.

